ELECTRIC TESTING OF TELEGRAPH CABLES

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TELEGRAPH CABLES.

A GUIDE

FOR THE

ELECTRIC TESTING

OF

TELEGRAPH CABLES.

BY

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PREFACE TO FIRST EDITION.

HAVING had the control of the manufacture of about 3500 nautical miles of Telegraph Cables, made mostly with Hooper's Core, but also with Core of ordinary Gutta-percha and of Willoughby Smith's Gutta-percha, I have had frequent opportunities of ascertaining the correctness of the data given in this book.

I do not expect an Electrician will discover anything new in these pages, but if he should find this Guide a useful one to put in the hands of young men who have to learn practical testing, I shall feel satisfied in having published it.

V. H.

LONDON, 1873.

PREFACE TO THIRD EDITION.

THE Congress of Electricians in 1881 have made some alterations necessary, and some few methods of testing have been added, in the hope of making this Guide more useful.

V. H.

COPENHAGEN, 1889.

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ELECTRIC TESTING

OF

TELEGRAPH CABLES.

1. ELECTRIC TESTS.

THE Electric Testing employed during the manufacture of cables, or cores, ascertains:

A. The Conductivity of the Copper.
B. The Charge of the Cable.
C. The Insulation of the Cable.
D. The Insulation of a Joint.
E. The Position and Magnitude of a Fault.

2. STANDARD DEGREE OF TEMPERATURE.

As the temperature has an essential influence on the conductivity of the copper and the insulation of the cable, all test-results ought to be reduced by calculation to a standard degree of temperature. For this purpose 75° Fahrenheit = c. 24° Centigrade has been chosen.

3. IMMERSION IN WATER.

The air not being so good an electric conductor as water, and the amount of the charge depending on how the

electricity in the copper conductor influences the water outside the dielectric, the cable has during the determination of its charge and its insulation to be immersed in water, the water to be in electric connection with the earth through an iron tank.

4. ARRANGEMENTS BEFORE TESTING.

When a cable has to be tested, it ought to be discharged, by connecting it to earth for some hours before the test.

A good earth connection may be obtained by using, in factories, gas or water pipes; on board cable ships, the iron hull of the ship; and with a submerged cable its iron wire sheathing.

During cable laying it is well to have one battery for the speaking instruments, and two testing batteries, as a single battery would become polarised. If Leclanché's cells be used, they should be filled with sawdust saturated with sal-ammoniac solution, and some water added every morning. The cells should be well insulated in a wooden tray, mounted on glass or earthenware supports.

All apparatus should be insulated by being placed on india-rubber or ebonite sheets, which should be well rubbed every morning, that humidity or dust may not destroy the insulation. Ebonite should be washed with boiling water, rinsed well in distilled water, and dried, to remove the film of acid produced, or its surface varnished with shellac.

It is advisable not to use leading wires, but, where possible, to take the ends of the cable, from which the sheathing has been removed, direct into the testing room.

When a cable end has to be insulated, the core must be uncovered for 18 inches, free from all hemp, iron wires, and if india-rubber core, free from all felt, and the conductor bared for one inch. One inch of the core near the conductor, and half an inch of the conductor near the core is then paraffined, and, during the insulation test, the end is left hanging in the air.

5. APPARATUS.

For electric tests the following apparatus are principally used:—

Batteries (B) up to 500 elements.
Thomson's Reflecting Galvanometer (G) with Shunt (Sh).
Condenser (Cd).
Reversing Battery Keys (BK).
Short-circuit Keys (SK).
Charge and Discharge Keys (DK).
Commutators (Cm).
Wheatstone's Bridge (WB) with Shunt (Sh).
Resistance-coil (R).

6. THE USE OF A SHUNT.

A shunt is generally used with a galvanometer, and in such a way that only a part of the electric current passes through the galvanometer, while the rest passes through the shunt. A properly proportioned shunt must be used in order that the deflection of the galvanometer needle may not be too large. The resistance of the shunt diminishes as

the length of the cable or the sensitiveness of the galvanometer increases.

The *multiplying power* or *value* v of the shunt is $= \frac{s+g}{s}$, where s is the resistance of the shunt, and g the resistance of the galvanometer. Should, for instance, s be $= 1$, and $g = 99$, v will be $= \frac{1+99}{1} = 100$; then only one hundredth part of the whole current will pass through the galvanometer, and the current will be 100 times greater than is indicated by the deflection of the galvanometer needle.

When it is desired to give the shunt a certain power, its *resistance* s can be found from the previous equation, as s is $= \frac{g}{v-1}$.

When a circuit includes a galvanometer of resistance g, and a shunt of resistance s, the total resistance of galvanometer and shunt is $\frac{g \times s}{g+s}$, and if it is required to maintain the resistance g of the circuit constant, then a resistance $g - \frac{g\,s}{g+s} = \frac{g^2}{g+s}$ must be added. In calculating insulation it is not necessary to account for the resistances g and s.

7. ELECTRIC UNITS.

The Congress of Electricians in Paris 1881, fixed the following electric units, based upon the fundamental units: 1 Centimètre, 1 Gramme, and 1 Second; or as it is called for brevity, the C. G. S. system.

The Unit of Resistance (R) is:

1 Ohm (ω), also called the Legal Ohm, or the Congress Ohm. It is = 10^9 C. G. S. units, and is the resistance of a prism of mercury, 1·06 mètre long, and 1 square millimètre in section, at 0° C.

The old Ohm, also called the British Association Unit, = 1 B. A. U., was the resistance of a prism of mercury, 1·0493 mètre long, and 1 square millimètre in section, at 0° C.

1 Siemens Unit = 1 S. U. is the resistance of a prism of mercury, 1 mètre long, and 1 square millimètre in section, at 0° C.

1 B. A. U. = 1·0493 S. U.

1 S. U. = 0·9536 B. A. U. = 0·943 legal Ohm.

(Professor Weber found 1 S. U. = 0·955 B. A. U., or 1 B. A. U. = 1·047 S. U.).

1 Megohm (Ω) = 1 Million Ohms.

The Unit of Electromotive Force (E) is:

1 Volt = 10^8 C. G. S. Units, and is about equal to the electromotive force of a Daniell's cell.

The Unit of Current Strength (C) is:

1 Ampère = 10^{-1} C. G. S. Units = $\dfrac{1 \text{ Volt}}{1 \text{ Ohm}}$.

1 Milliampère = $\frac{1}{1000}$ Ampère.

The Unit of Quantity (Q) is:

1 Coulomb = 10^{-1} C. G. S. Units = 1 Ampère per second.

The Unit of Capacity or Charge (K) is:

1 Farad = 10^{-9} C. G. S. Units = $\dfrac{1 \text{ Coulomb}}{1 \text{ Volt}}$, or, to quote the words of Sir William Thomson, when explaining the

practical units, "1 Farad is the capacity of a condenser, which holds one Coulomb, when the difference of potential of its two plates is one Volt."

1 Microfarad = 1 millionth part of a Farad.

8. THE ORDER OF THE TESTS.

The Tests are best taken in the following order:

Resistance of the Galvanometer.
Conductivity of the Copper.
Charge of the Leading wires.
,, of the Cable after 1 minute's Insulation.
,, ,, by instantaneous Discharge.
Constant c of the Condenser.
Constant n of the Battery.
Constant ϕ of the Galvanometer.
Insulation of the Leading wires.
Insulation of the Cable.

A.—THE CONDUCTIVITY OF THE COPPER.

9. EXPLANATION OF THE METHOD.

In this electric test of the cable, the positive current from the copper, C, *Fig.* 1, in the battery (B) is generally put to earth (E).

The negative current from the zinc (Z) is put through a wire (W) to the Wheatstone bridge (WB) and divides at a

into two parts; one passes through $a\,c$ and the cable (Ca) to earth, and the other through $a\,b$ and the resistance-coil (R) to earth. The connection to earth can be omitted, and C directly connected to d.

By removing the plug e, the current through $b\,c$ passes through the galvanometer (G) with shunt (Sh). There will be no current through $b\,c$, and no deflection of the galvanometer needle, if the two currents $a\,b\,d$ and $a\,c\,d$ are of the same potential at b and at c. This occurs when

the resistance in $a\,b$: the resistance in $a\,c$ = the resistance in R: the resistance in Ca

$$\text{or, } \frac{a\,b}{a\,c} = \frac{\mathrm{R}}{\mathrm{Ca}}; \text{ or, } \mathrm{Ca} = \frac{a\,c}{a\,b}\mathrm{R} = \mathrm{R}'.$$

From $a\,c = a\,b$, Ca = R. The proportion between the resistance $a\,c$ and $a\,b$ can be varied from $\frac{1000}{10}$ to $\frac{10}{1000}$, and this proportion is termed the *ratio of balance.*

The resistance R is now to be varied until the spot of light from the galvanometer covers the zero on the scale; it will perhaps be found that the spot of light moves to the left in diminishing R, that is by inserting a plug into the resistance-coil. The plugs in the resistance-coil must be carefully kept clean.

As a paid-out cable is more or less affected by *earth-currents,* it is necessary to test it alternately with the zinc and copper-poles. If the earth-current be weak, and the difference between the zinc and the copper-readings small, the arithmetic mean of the tests will give the resistance of the cable; but when the earth-current is strong, it is

advisable to increase the strength of the testing battery, and to calculate the resistance by the formula $\sqrt{r.R}$, where r is the resistance obtained when the cable is connected with the zinc-pole, and R that with the copper-pole.

Earth-currents are always present, varying both in direction and strength, sometimes slowly and sometimes rapidly, and appear to have daily two maxima of positive and two of negative currents. Lines running east and west are more affected by earth-currents than those running north and outh; and Aurora Borealis, thunderstorms, and earthquakes are generally preceded, accompanied, or followed by currents of great strength, entirely overcoming the working currents.

A *second method* for finding the copper-resistance has been recommended. Having arranged the connections for copper-resistance as in *Fig.* 2, and connected one end of the cable to n of the Wheatstone bridge, the other cable end being put to earth at the distant station, the key SK is depressed, and the deflection from the earth-current through the galvanometer and a proper shunt noted; f of the reversing key (BK) is next depressed, to put the battery in action through the cable and resistance-coil. To give the earth-current the least possible time to alter, the plugs of the resistance-coil are now adjusted as quickly as possible, until the spot of light covers that division on the scale where the deflection from the earth-current was observed, i. e. the so-called "false zero." If necessary, the position of the deflection of the earth-current may again be observed, and another reading of the resistance in the bridge taken; but when the earth-current is steady, one reading either with

the zinc or with the copper-pole will be sufficient, and give as satisfactory a result as a long series of readings alternately with zinc and copper-currents in the usual manner.

Sir William Thomson recommends a *third method,* stating that during the tests for copper-resistance of the Direct United States Cable, differences of potential between the Irish and Nova Scotian earths were found varying rapidly in amount from 5 to 18 cells, but always in the same direction. The ordinary bridge method would have given no result at all in so disturbed a condition of the cable, but the method by simple deflection was used. A time of comparative tranquillity was chosen, a reading taken, and the galvanometer then as quickly as possible short-circuited, the battery reversed, the galvanometer circuit re-opened, and a fresh reading taken. Half the space travelled by the spot of light from the first reading to the second is taken as being the deflection that would be produced by the battery applied in either direction were there no earth-current.

This was done seven times, and the half range found to be 232·3. Immediately after it was found that the same battery applied in two directions through the galvanometer and 7300 Siemens' units gave 232 divisions on one side of zero, and 233 on the other—mean 232·5. Then the copper-resistance to be inferred from the observations is

$$\frac{232 \cdot 5}{232 \cdot 3} \times 7300 = 7306 \text{ Siemens' units.}$$

10. PRACTICAL EXECUTION OF THE TEST.

For the ordinary test the apparatus indicated in Fig. 2 is used.

The copper-pole (C) of the battery (B) is, by lifting *g*, connected, through *i* and *l* in the key BK, to the screw *m* in the resistance-coil (R); the zinc-pole (Z) is connected, by depressing *f*, through *h* and *k* in the key BK, to the screw *z* in the Wheatstone bridge. The battery consists of 4 to 10 cells.

The two ends *n* and *o* of the balance branches are directly connected with the bridge *d e* of the galvanometer. The ratio of balance is generally for the testing of the core and of the leading wires $= \frac{1000}{10}$, of the cable $= \frac{1000}{100}$, and of the galvanometer $= \frac{1000}{1000}$.

One end of the cable is connected to *m*, the other to *n*.

When *f* is depressed the current traverses the cable and the resistance R, which is varied until there is no deflection of the galvanometer.

The resistance of the cable is now calculated by the ratio of balance and the indicated resistance (R).

The resistance of the leading wires is found in the same way as the resistance of the cable, by removing the cable, and connecting only the leading wires between *m* and *n*.

11. CALCULATION OF THE CONDUCTIVITY.

The resistance of the cable and leading wires being $= R'$, and the resistance of the leading wires $= L$, the resistance R_2 of the cable only will be $= R' - L$.

The *Ohm,* is used as the unit of resistance.

The length of the cable being $= l$ knots, or nautical miles, the resistance per knot will be:

$$\frac{R_2}{l}.$$

As the resistance of the copper increases ·21 per cent., or ·0021 for every degree Fahrenheit increase of temperature, when the test is made at a temperature t, the resistance at 75° F. will practically be:

$$\frac{R_2\,(1 + \cdot 0021\,(75^\circ - t)\,)}{l}$$

Supposing the resistance R_2 to have been found at 85°, the resistance at 75° will be: $R^2\,(1 - (\cdot 0021 \times 10)) = \cdot 979\,R_2$, see Table I.

As a wire of pure copper with the length of 1 knot and the weight of 1 lb. has at 75° F. a resistance of 1192·33 Ohms, a wire with the weight of P lbs. per knot will have a resistance of $\frac{1192 \cdot 33}{P}$ Ohms. The core of the China-Japan Cable, with a weight of 300 lbs. copper per knot, would therefore have a resistance $= \frac{1192 \cdot 33}{300} = 3 \cdot 9744$ Ohms, if it were of pure copper.

The conductivity of the copper conductor of this cable, expressed in a percentage of the conductivity of pure copper, or the *specific conductivity* of the conductor, is therefore:

$$x = \frac{3 \cdot 9744 \times 100 \times l}{R_2\,(1 + \cdot 0021\,(75\text{-}t)\,)}.$$

Generally, several cables are tested at the same time, and the calculation is then facilitated by the use of logarithms, which are best taken in the following order:

$$\log. x = -\log. R_2 - \log. (1 + \cdot 0021\,(75\text{-}t)) + \log. l$$
$$+ \log. 3 \cdot 9744 + \log. 100.$$

12. THE RESISTANCE OF THE GALVANOMETER.

The resistance of the galvanometer, used to ascertain the charge and the insulation of the cable, has to be found in the same way as the resistance of the cable, by placing the galvanometer instead of the cable between m and n, Fig. 2. The ratio of balance will be $= \frac{1000}{1000}$.

If *only one galvanometer* is to be had, its resistance can be found thus:—The resistance of the galvanometer at a certain degree F. being always exactly given by its manufacturer, its resistance at the temperature during testing, read from a thermometer fixed to the galvanometer, is easily calculated by the preceding rule. A Table for the resistances between 40° and 75° F. ought to be calculated for each galvanometer, and its correctness ascertained by comparison with the resistances obtained by measurement with a second galvanometer.

If the resistance of the galvanometer at 60° F. is 10600 Ohms, its resistance at 65° F. will be:

$$10600\,(1 + \cdot 0021 \times 5) = 10711 \text{ Ohms.}$$

A *second method* of finding the resistance R of the galvanometer, when only one galvanometer is at hand,

consists in inserting between c and d of the Wheatstone bridge, Fig. 1, the shunt Sh, finding its resistances r.

$$
\begin{array}{llll}
\text{If Sh} = \frac{1}{999}, & r \text{ may be} = & 11 \cdot 00 \text{ and R is} & = 10989 \\
\quad = \frac{1}{99} & = & 110 \cdot 70 & = 10959 \\
\quad = \frac{1}{9} & = & 1214 \cdot 00 & = 10926
\end{array}
$$

The mean of these three resistances R gives the true resistance R = 10958.

13. THE RESISTANCE OF THE BATTERY.

To find the resistance of a battery, connect its copper-pole C, Fig. 2, to earth, and its zinc-pole with the button e of the galvanometer. Connect the two buttons, e and d, of the galvanometer by a copper wire of small resistance, and put d to earth. By depressing f, the current passes to earth through the shunted galvanometer, the resistance of which is so small that it may be neglected, and a certain deflection u is found on the scale. Then put between the zinc-pole and the galvanometer a resistance R so great that the deflection is only $= \frac{u}{2}$; R will be = the resistance of the battery.

With a Daniell's battery of 140 cells, and a galvanometer with a resistance of 10,700 Ohms, a copper wire with a resistance of ·2 Ohm was used, and a deflection of 120° obtained. By placing in the circuit a resistance of 3500 Ohms, the deflection of 60° occurred; the resistance of the battery was therefore 3500 Ohms, or 25 Ohms per cell.

If a battery, such as Leclanché's, becomes polarised when working on short circuit, its resistance may be determined by a *second method*, by putting between the zinc-pole and the galvanometer, not shunted, which has a resistance g, a resistance r, giving a deflection u'; this resistance is increased to R, giving a deflection $\frac{u'}{2}$; the resistance x of the battery is then found by:

$$\frac{u'}{\frac{1}{2}u'} = \frac{x + R + g}{x + r + g}; \text{ or, } x = R - 2r - g.$$

If g is so small compared to R that it may be neglected, then

$$x = R - 2r.$$

If the deflection is halved by increasing the resistance from 4000 to 10,000 Ohms, the resistance of the battery is 2000 Ohms.

The resistance of the battery may be determined by a *third method*, by first using a resistance r, and the galvanometer shunted with a resistance s, giving a deflection u'; by removing the shunt and inserting a resistance R the same deflection u' is obtained; E is = the electromotive force. We find:

$$\frac{E}{x + \frac{s(r+g)}{s+r+g}} \cdot \frac{s}{s+r+g} = \frac{Es}{x(s+r+g)+s(r+g)} = \frac{E}{x + R + g}$$

$$x = s\frac{R - r}{g + r}.$$

If $g + r$ is made $= s$, then: $x = R - r$.

14. THE RESISTANCE OFFERED BY THE EARTH PLATE.

To detect that an earth-plate offers resistance, one cell is connected by its copper-pole to earth, and by its zinc-pole through the galvanometer to another earth; a certain deflection is then found on the galvanometer scale. The two wires, one from the copper-pole and the other from the galvanometer, are then connected together, instead of being both put to earth, and the deflection will be the same as before, if the earth-plates are in good order. Should the latter deflection be greater than the former, the earth connection is faulty; and as this often arises from the earth being dry, this fault may often be prevented by keeping the earth around the plate drenched with water.

15. EXAMPLES.

Example 1.

Length of the core	=	5 knots.
Temperature	=	70° F.
Number of elements in the battery	=	4.
Ratio of balance	=	$\frac{1000}{10}$.

During testing, the following columns in a *journal* are daily to be filled up. Columns 1 and 2 are given; cols. 3, 4, and 9 are read from the resistance-box; and cols. 5 to 8 are to be calculated.

Length of Core in Knots.	Temperature.	Measured Resistance of Leading Wires.	Measured Resistance of Core and Leading Wires.	True Resistance of Core.	Resistance at 75° F.	Resistance per Knot at 75° F.	Specific Conductivity.	Resistance of Galvanometer.
1	2	3	4	5	6	7	8	9
5·000	70°	130	2244	21·14	21·36	4·272	93·03	5850

The true resistance of the core is the resistance of the core and leading wires, minus the resistance of the leading wires, divided by the ratio of balance, or:

$$\frac{2244 - 130}{\frac{1000}{10}} = 21 \cdot 14 \text{ Ohms.}$$

As the test has been taken at a temperature of 70° F. the resistance at 75° F. will be:

$$21 \cdot 14\,(1 + \cdot 0021 \times 5) = 21 \cdot 36 \text{ Ohms.}$$

And as the length of the core is 5 knots, the *resistance per knot*, at 75°, is:

$$\frac{21 \cdot 36}{5} = 4 \cdot 272 \text{ Ohms.}$$

The resistance of a pure copper conductor with a weight of 300 lbs. per knot being 3·9744 Ohms, the *specific conductivity* of the copper conductor will be:

$$\frac{3 \cdot 9744 \times 100}{4 \cdot 272} = 93 \cdot 03.$$

The conductivity is calculated by using logarithms as follows:

$$\log. x = -\log. 21 \cdot 14 - \log. 1 \cdot 0105 + \log. 5 + \log. 3 \cdot 9744 + \log. 100,$$

$$\begin{array}{lrl} \text{or } \log. 21\cdot14 & = 1\cdot3251050 & \\ \log.\ 1\cdot0105 & = 0\cdot0045363 & \\ & \overline{} & 1\cdot3296413 \\ \log.\ 5 & = 0\cdot6989700 & \\ \log.\ 3\cdot9744 & = 0\cdot5992716 & \\ \log.\ 100 & = 2\cdot0000000 & \\ & \overline{} & 3\cdot2982416 \\ & & \overline{} \\ & \log. x = & 1\cdot9686003 \\ & x = & 93\cdot03 \end{array}$$

Example 2.

Length of the cable .. .. = 100 knots.
Temperature .. .. .. = 70° F.
Number of cells .. .. = 5.
Ratio of balance .. .. = $\frac{1000}{100}$.

The following results were found:

Length of Cable in Knots.	Temperature.	Measured Resistance of Leading Wires.	Measured Resistance of Cable and Leading Wires.	True Resistance of Cable.	Resistance at 75° F.	Resistance per Knot at 75° F.	Specific Conductivity.	Resistance of Galvanometer.
1	2	3	4	5	6	7	8	9
100	70°	31·3	4260·3	422·9	427·3	4·273	93·00	5955

B.—THE CHARGE OF THE CABLE.

16. PRACTICAL EXECUTION OF THE TEST.

The arrangement of the apparatus is indicated in *Fig. 3a.* The copper-pole C of the battery B is connected through the key BK to earth, and the zinc-pole Z through the key BK to the screw *s* of the discharge-key DK.

The screw *s* of the charge or discharge-key DK being connected to the zinc-pole, the screw *t* is connected to earth through the shunted galvanometer, and the screw *u* is connected to one end of the cable through the plug *p* of the commutator Cm.

The other end of the cable is well insulated.

The end screws *m* and *n* of the shunt Sh are connected to the screws *e* and *d* in the bridge of the galvanometer. With a battery of 10 cells, a shunt may be used at the cable, varying from 200 to 10, as the length of the cable is increased from 10 to 200, the shunt multiplied by the length or the charge of the cable always giving the same value. Suppose a shunt of 2000 used with a condenser having a capacity of ·5 microfarad; the shunt of 2000 multiplied by the charge ·5 is = 1000.

When the cable has been charged for one minute by depressing the button *q* of the discharge-key, *q* is released and *r* depressed, and the cable will be discharged to earth through the shunted galvanometer.

300° to the right of zero may be taken as the starting point, so as to afford as large as possible a deflection on the scale of the galvanometer. The deflections are then read to the left.

To find the charge or the electro-static capacity of the Direct United States Cable, Sir Wm. Thomson employed *another method:*

By depressing the arm f of the battery-key BK, *Fig.* 3*b*, the current from a well-insulated battery of 80 cells was kept flowing on the one side through a resistance of 20,000 units, and on the other through a variable resistance R to earth. By depressing the arm q, the condensers of a total capacity of 80 microfarads were connected to the resistance of 20,000 units, and by depressing the arm r the cable was connected to the resistance R, and the condensers and the cable were charged to opposite potentials, which were found equal when the resistance R was 1615 units. When the condensers and the cable were then connected for 5 seconds, by inserting the plug p in Cm, and, by inserting the plug p', discharged through a galvanometer G, well shunted to avoid over sensitiveness, no deflection was obtained. The capacity of the cable was $\frac{20{,}000}{1615} \times 80 = 991$ microfarads, or as the length of the cable was 2420 knots, the capacity was $0 \cdot 409$ microfarad per knot.

17. CONSTANT c OF THE CONDENSER.

For the determination of the charge a condenser is used the capacity of which is known. In the core factory the capacity of the condenser was $\cdot 319$ microfarad; in the cable factory it was $\cdot 50$ microfarad.

When the charge of the condenser is to be measured, the condenser, instead of the cable, is charged, by removing the plug p to p', Fig. 3*a*. One screw of the condenser is

joined through the plug p' in the commutator Cm, and through u and s in the discharge-key to the zinc-pole; its other screw is put to earth. The condenser is charged for 1 minute by depressing q; it is then discharged instantaneously through the shunted galvanometer, by releasing q and depressing r. In reading the deflection U_3, which generally is put = *constant* c, a shunt should be used of such a value that the deflection with the condenser is the same, or about the same, as the deflection with the cable.

18. CALCULATION OF THE CHARGE.

The cable and the leading wires are charged for 1 minute, then insulated for 1 minute, by releasing q, Fig. $3a$; then discharged by depressing r; the charge passes through the galvanometer to earth, and on the scale of the galvanometer a deflection U will be obtained.

The cable is then charged for 1 minute and instantaneously discharged, a deflection U′ being obtained.

The percentage *loss of charge* in the cable in 1 minute is then:

$$\frac{U' - U}{U'} \times 100.$$

The leading wire, when charged for 1 minute and instantaneously discharged, gives a deflection = u. The charge of the cable alone after 1 minute is then expressed by:

$$U' - u = U_2.$$

The condenser, when charged in 1 minute and instantly discharged, gives a deflection U_3, which is generally termed the *constant* c.

It is advisable to ascertain the state of the insulation of the condenser by charging it through the galvanometer; if the condenser is well insulated the spot of light will immediately return to zero when the charge is completed, whilst if it is faulty a constant deflection will be observed.

With cables of short length, and with leading wires and the condenser, it is sufficient to charge for 15 seconds instead of 1 minute, where rapidity is required.

If the condenser has an inductive capacity C, then the *specific inductive capacity* x of the cable is expressed by:

$$\frac{U_3}{C} = \frac{U_2}{x}; \text{ or, } x = \frac{U_2 \times C}{U_3} = \frac{U_2 \times C}{c}.$$

When a shunt with a resistance s has been used with the cable, and has a multiplying power $v = \frac{s + g}{s}$, where g is the resistance of the galvanometer; and when a shunt with a resistance s' has been used with the condenser, and has a multiplying power $v' = \frac{s' + g}{s'}$; the deflection c has to be multiplied by v' and divided by v, then:

$$\frac{U_2 \times C}{c \times \frac{v'}{v}} = \frac{U_2 \times v \times C}{c \times v'}.$$

As the inductive capacity of a cable is directly proportionate to its length, the *inductive capacity per knot,* when the cable has a length l, will be:

$$x = \frac{U_2 \times v \times C}{c \times v' \times l}.$$

If logarithms are used the formula will be:

$$\log. x = \log. C + \log. v + \log. U_2 - \log. c - \log. v' - \log. l.$$

19. EXAMPLES.

Example 1.

Length of core	=	5 knots.
Number of cells	=	20.
Inductive capacity of the condenser	=	·319 microfarad.
Shunt with the core	=	100 Ohms.
Shunt with the condenser	=	500 Ohms.
Resistance of the galvanometer ..	=	5850 Ohms.
Deflection from discharge of the leading wires	=	2.

The following journal is daily to be kept:

Shunt with the Core.	Deflection after 1m Charge and 1m Insulation.	Instantaneous Deflection after 1m Charge.	Percentage Loss of Charge.	Shunt with the Condenser.	Deflection from Condenser = c.	Total Charge.	Charge per Knot.
1	2	3	4	5	6	7	8
100	652°	662°	1·51	500	450°	2·199	·4398

The deflections 2, 3, and 6 are read to the left of the scale, with 300° to the right of zero as starting point. The deflections noted under 2 and 3 are the deflections from which are subtracted the deflection from the leading wires.

The percentage loss of charge is:

$$\frac{662 - 652}{662} \times 100 = 1{\cdot}51.$$

As the shunt with the core has a multiplying power $v = \dfrac{100 + 5850}{100} = 59{\cdot}50$, and the shunt with the condenser

a multiplying power $v' = \dfrac{500 + 5850}{500} = 12{\cdot}70$, the reduced deflection of the condenser is $= 450 \times \dfrac{12{\cdot}70}{59{\cdot}50} = 96{\cdot}05$.

The whole inductive capacity of the core is:

$$\frac{{\cdot}319}{96{\cdot}05} = \frac{x}{662}$$

$$x = \frac{{\cdot}319 \times 662}{96{\cdot}05} = 2{\cdot}199.$$

The inductive capacity per knot of the core is:

$$\frac{2{\cdot}199}{5} = {\cdot}4398.$$

When logarithms are used:

$$\log. x = \log. {\cdot}319 + \log. 59{\cdot}50 + \log. 662 - \log. 450 - \log. 12{\cdot}70 - \log. 5.$$

$$\begin{array}{lll}
\log. \ {\cdot}319 & = 0{\cdot}5037907 - 1 & \\
\log. \ 59{\cdot}50 & = 1{\cdot}7745170 & \\
\log. \ 662 & = 2{\cdot}8208580 & \\
 & \overline{} & 4{\cdot}0991657 \\
\log. \ 450 & = 2{\cdot}6532125 & \\
\log. \ 12{\cdot}70 & = 1{\cdot}1038037 & \\
 & \overline{} & 3{\cdot}7570162 \\
 & \log. \ 2{\cdot}199 & = 0{\cdot}3421495 \\
 & \log. \ 5 & = 0{\cdot}6989700 \\
 & & \overline{} \\
 & \log. \ x & = 0{\cdot}6431795 - 1 \\
 & x & = 0{\cdot}4398
\end{array}$$

Example 2.

Length of cable	=	100 knots.
Number of cells	=	10.
Charge of the condenser	=	·50 microfarad.

Shunt with the cable .. .. = 20 Ohms.
Shunt with the condenser .. .. = 2000 Ohms.
Resistance of galvanometer .. = 5955 Ohms.
Deflection from the leading wires = 0.

Shunt with the Cable.	Deflection after 1^{m} Charge and 1^{m} Insulation.	Instantaneous Deflection after 1^{m} Charge.	Percentage Loss of Charge.	Shunt with the Condenser.	Deflection from Condenser.	Total Charge.	Charge per Knot.
1	2	3	4	5	6	7	8
20	482°	489°	1·50	2000	418°	44·0	0·4400

C.—THE INSULATION OF THE CABLE.

20. PRACTICAL EXECUTION OF THE TEST.

The arrangement of the apparatus is indicated in *Fig.* 4. The copper-pole of the battery is connected to earth, and the zinc-pole to the screw *b* of the short-circuit key SK; one end of the cable is connected to the screw *c* of the key SK, whilst its other end is well insulated.

When *f* is depressed, the current from Z passes through the short-circuit key from *b* through *c* into the cable, the other end of which is insulated, so that the current is obliged to pass through the dielectric to earth. In order that the charging current may not affect the galvanometer, the button *a* is not depressed, and the galvanometer put into the circuit, until ½ minute after the circuit is closed. When *a* is depressed, the current on arriving at *b* and *e*, on its way into the cable, will divide into two parts, of which the one

passes through the shunt Sh, the other through the galvanometer G, the deflection of which measures the strength of the current. The resistance which the currents meet with in the dielectric so far surpasses all the other resistances that it is unnecessary to take notice of the latter. It is therefore supposed that the deflection is in inverse proportion to the resistance of the dielectric alone.

If the insulation of a core or submerged cable is very low, say under 1,000,000 Ohms, it can be found in the same way as the copper-resistance (Fig. 2), the core or cable being connected to the screw n of the resistance-box, and having the other end insulated. The ratio of balance multiplied by the resistance R gives the insulation of the cable.

21. OHM'S LAW.

According to Ohm's Law:

$$\text{the strength of the current} = \frac{\text{The electromotive force E}}{\text{Resistance } x}.$$

As the strength of the current is here measured by the deflection U of the galvanometer,

$$U = \frac{E}{x}, \text{ or}$$

$$\text{the resistance } x \text{ of the Insulation} = \frac{E}{U}.$$

As E and U vary daily, E depending not only on the number, but on the strength of the cells, and U on the sensitiveness of the galvanometer, these two factors must daily be measured in reference to some unit.

22. CONSTANT n OF THE BATTERY.

The electro-motive force of the battery is measured by reference to the electro-motive force of one single cell, or by the constant n. This is determined by charging the condenser instead of the cable (see *Fig.* 5) and removing the plug p to p'.

The condenser is first charged during 1 minute from 1 cell, through s and u in the discharge-key by depressing q. By releasing q and depressing r, the condenser is discharged to earth through the galvanometer; the deflection u is noted. The condenser is now again charged, but with the whole battery, by removing the wire v and connecting the wire x to the screw s, and a *shunt* is now used, which is *varied* until the deflection is $= u$ as before. If the shunt has a resistance $= s$, and the galvanometer a resistance $= g$, the multiplying power of the shunt will be $= \frac{s + g}{s}$ which may be put $= n$, and the battery will thus work with a strength of n cells.

Instead of the variable shunt, a *constant shunt* is generally used, and the two discharges then give two different deflections: u and u'. The constant n is then $= \frac{u'}{u}$. Should with u' a shunt v_2 have been used, then $n = \frac{v_2 \, u'}{u}$.

23. CONSTANT ϕ OF THE GALVANOMETER.

The sensitiveness of the galvanometer, evaluated by the constant ϕ, is determined as follows: only 1 *cell is used* as a battery (*Fig.* 6); one end of a resistance-coil of 10,000 ohms

is connected to the cell; its other end being connected to earth, through the key SK and the galvanometer. A shunt with resistance s' and multiplying power v' is used. When a deflection ϕ has thus been obtained, we find according to Ohm's Law:

$$v'\phi = \frac{1}{10000} \text{ Ohms.}$$

If a sufficiently high resistance, including the resistance b of the battery, g of the galvanometer, and s of the shunt, or $b + \frac{g\,s}{g + s}$, say of 2,000,000 Ohms, is attainable, or if the galvanometer is very slightly sensitive, the constant ϕ of the galvanometer may be determined by using *the whole battery* of, say, 200 cells; the resistance of the battery, say, 25 Ohms per cell, has then to be added to the resistance of the coil. The use of such a high resistance facilitates the test, as it is not necessary to determine the constant of the battery, that is, the electro-motive force of the battery compared with the electro-motive force of one cell.

24. CALCULATION OF THE INSULATION.

The current is first led only into the leading wires, which are not yet connected to the cable. After $\frac{1}{2}$ minute the plug of the galvanometer is removed, and after another $\frac{1}{2}$ minute the deflection u', is read. If the deflection *after* 1 *minute* from cable and leading wires is U, then the deflection from the cable only will be:

$$\mathrm{U} - u' = \mathrm{U}'.$$

If a shunt s with a multiplying power v has been used, the deflection U′ has to be multiplied by v, and $v\,\mathrm{U}'$ is a

measure for the insulation. The resistance s of the shunt will be in inverse proportion to the length of the cable.

The shunt as well as the galvanometer has always to be well insulated.

It should be observed that the deflection ϕ is taken on the same side of zero of the scale, and, if possible, at nearly the same point of the scale, as the deflection U′ from the cable.

When these two deflections are compared, we obtain:

$$v'\phi : v\,\mathrm{U}' = \frac{1}{10000} : \frac{n}{x},$$

or the resistance x of the insulation is

$$= \frac{n \times v' \times \phi \times 10000}{v\,\mathrm{U}'}.$$

If the galvanometer is feebly sensitive, the constant ϕ can be determined from the whole battery, that is to say, from n elements, and should a shunt be used with the multiplying power v_2:

$$v_2\phi = \frac{n}{10000}, \text{ or } x = \frac{v_2 \times \phi\, 10000}{v\,\mathrm{U}'}.$$

This equation being independent of n, it is in this case unnecessary to know the strength of the battery.

As the insulation is in inverse proportion to the length of the cable, which can be put $= l$ knots, the *insulation per knot* will be

$$= \frac{n \times v' \times \phi \times 10000 \times l}{v\,\mathrm{U}'}.$$

The resistance of the insulation diminishes as the *temperature* increases, and if the resistance $x\,l$ is measured at, for instance, t degress below or above 75° F., the resistance

calculated at 75° F. will, with Hooper's core, be $\frac{x\,l}{1 \cdot 026^t}$, or $x\,l \times 1 \cdot 026^t$ (see Table II.). This number, with which it has been necessary to divide or multiply the result, so as to reduce from one temperature to another, is termed the temperature coefficient. When therefore the insulation has been measured at t degrees below 75°, the insulation per knot at 75° will be

$$= \frac{n \times v' \times \phi\, 10000 \times l}{v \times U' \times 1 \cdot 026^t}.$$

The resistance at 75° F. for gutta-percha will be found by using in the formula, instead of $1 \cdot 026^t$ as with Hooper's core, $1 \cdot 076^t$ with ordinary gutta-percha (see Table III.), and $1 \cdot 080^t$ with Willoughby Smith's gutta-percha (see Table IV.).

If the constant of the galvanometer is taken with the whole battery, a shunt $v' = 100$, and a resistance of 10,000 Ohms, then the insulation at the observed temperature will be $= \frac{\phi\, l}{v\, u'}$, megohms.

When the temperature cannot be correctly measured by a thermometer, as when the cable is in a tank, sometimes full of water, sometimes without, or when it is paid out into the sea, the temperature of the cable may be calculated by its copper resistance, when this resistance at 75° F. is known.

If the resistance of a cable per knot at 75° F. is known to be 4·25 Ohms, and the measured resistance is 4·00, then the temperature of the cable is found as follows:

$$4 \cdot 25 = 4 \cdot 00\,(1 + \cdot 0021\,(75 - t°)\,)$$

or

$$\frac{4 \cdot 25 - 4 \cdot 00}{4 \cdot 00} = \cdot 0021\ (75\text{-}t^\circ),$$

$$t^\circ = 75^\circ - \frac{4 \cdot 25 - 4 \cdot 00}{\cdot 0021 \times 4 \cdot 00}$$

which gives

$$t = 45^\circ.$$

If it should be required to determine the insulation *after 2 minutes'* electrification, the deflection is read after 2 minutes, and the calculation made as previously described.

If the calculation be made by logarithms, the following formula is used:

$$\log. x = \log. n + \log. v' + \log. \phi + \log. 10000 - t \log. 1 \cdot 026 - \log. v - \log. U' + \log. l.$$

25. INSULATION TEST BY LOSS OF CHARGE.

The spot of light reflected on to the scale of the galvanometer is often very unsteady during the insulation test. This may be caused by the battery being strongly polarized, or by the connection to earth being faulty, or by adjoining machines making the test-table shake, or by cables being coiled into tanks near to the cable under test, or in a laid cable by earth-currents. This unsteady deflection occurs particularly with india-rubber cables.

For india-rubber cables it may be advisable to confirm the insulation test by determining the loss of charge. If a cable, charged from a battery of 10 to 20 cells for 1 minute, insulated for 1 minute ($= t$) and discharged, gives the deflection u'; and the same cable, charged for 1 minute and then instantly discharged, gives a deflection u, then the charge will fall to *half charge* in t' minutes, and

$$t' = \frac{\log. \frac{1}{\cdot 5}}{\log. \frac{u}{u'}} t = \frac{0\cdot 30103}{\log. \frac{u}{u'}} t.$$

The *insulation resistance per knot* in megohms may then be expressed by $\frac{1\cdot 443 \times 60 \times t'}{C} = \frac{\cdot 4343 \times 60 \times t}{C \log. \frac{u}{u'}}$,

where C is the charge in microfarads per knot, and t is expressed in minutes.

The resistance found in this way will generally be higher than that taken directly after 1 minute's insulation, and agrees better with the resistance of the 2 minute, and which depends on the absorption of electricity by the dielectric, or the electrification of the cable until it is fully charged.

EXAMPLE.—If the deflection falls in 1 minute from 100 to 98·5,

$$t' = \frac{0\cdot 30103}{\log. \frac{100}{98\cdot 5}} = \frac{0\cdot 30103}{0\cdot 00655} = 46^m.$$

The insulation resistance at the existing temperature is

$$= \frac{1\cdot 443 \times 60 \times 46}{0\cdot 46} = 8658 \text{ megohms.}$$

Another method is, when cables of high insulation resistance have to be compared, to charge the cable through the shunted galvanometer for 10 seconds, reading the immediate deflection u; then to insulate the cable for 1 minute, and recharge it through the galvanometer without shunt, reading the immediate deflection u', which indicates the

quantity of electricity required to refill the cable to its original charge. The shunt may be given such a resistance that the deflection u with a good cable is equal to u'. Different cables may then be easily compared with this one.

26. INSULATION TEST BY THE ELECTROMETER.

The insulation of a cable may be found by means of an electrometer, and this instrument enables us to notice the continuous fall of charge in a cable. A very thin, flat aluminium needle is suspended between two plates, charged with electricity. If the needle has a negative charge, it will be repelled from the one plate, which is negative relative to the other plate, and the motion of the needle will be indicated by the motion of the spot of light, reflected by a mirror attached to the needle; the deflection will be sensibly proportional to the difference of charge in the two plates.

One pole of the battery is to earth, its other pole is permanently connected with one plate of the electrometer, and by a short contact of 15 seconds with the other plate, which is in connection with the cable. The two plates are therefore, when the short contact is first broken, at the same potential or electro-motive force; but the potential of the plate connected with the cable will fall, in consequence of the leakage through the dielectric of the cable, while the potential of the other plate will remain unchanged, and the spot of light will move from its first undeflected position.

As the deflection ought only to increase in a certain proportion, the condition of the cable may be ascertained by observing the deflection every fifth or tenth minute.

The *insulation* I of a cable, in megohms per knot, is calculated by the following formula :

$$I = \frac{\cdot 4343\, t}{C \log. \dfrac{u}{u_1}},$$

where C is the charge in microfarads, u the first observed deflection on the electrometer scale, and u_1 the deflection after any time t, expressed in seconds.

EXAMPLE.—If the deflection after $1^m\ 45^s$ is 395, and after $2^m\ 15^s$ is 391·5, and the charge is = ·44, then:

$$I = \frac{\cdot 4343 \times 30}{\cdot 44 \times \log. \dfrac{395}{391 \cdot 5}} = 7660 \text{ megohms.}$$

The electrometer can be used in every test, when a condenser is ordinarily employed, by substituting the electrometer for the condenser and the galvanometer.

The electrometer is supposed to have, compared with the galvanometer, some advantages, when used for testing short coils of high dielectric resistance, or cables in course of sheathing, while machinery is in motion, or for testing several cables at the same time, especially when tests of long electrification are taken, or for testing a paid-out cable affected by earth-currents. But if the electrometer is damp, its indications are incorrect, and as, in spite of every precaution, it is difficult to keep it from effects of moisture, the insulation test of a cable should not depend only on measurement with an electrometer.

27. STRONG BATTERIES WITH CHANGING CURRENTS.

It is desirable at the daily testing of an india-rubber core to have, for half an hour before testing, a battery of 500 cells with reversing currents connected to the core. The *insulation test* is then to be taken by connecting the core, first, for 5 minutes to the zinc-pole of the battery, reversing the current for 2 minutes, leaving the core to earth until it is quite discharged, and then connecting it for 5 minutes to the copper-pole, noting the deflection at every minute; the deflections obtained from both currents ought to fall in the same proportion. With a standard Hooper's core, the deflection at the fifth minute is half the deflection at the second minute.

The same operation is performed at the *final test* of a cable, only the deflections are in this case noted for 15 minutes, instead of 5 minutes.

28. EXAMPLES.

Example 1.

Length of india-rubber core ..	=	5 knots.
Temperature	=	70° F.
Number of elements (generally 250) here	=	100.
Resistance of galvanometer ..	=	5850.
Deflection from the leading wires	=	3.
Shunt with core	=	0; $v = \infty$.
Shunt with galvanometer ..	=	10 Ohms; $v' = 586$.
Shunt with battery	=	100 Ohms; $v_2 = 59 \cdot 5$.

The following eight columns are to be filled up in a journal; 1, 3, and 5 are given, 4 and 6 are read, and the others are calculated.

Shunt with Battery.	Constant n of Battery.	Shunt with Galvanometer.	Constant ϕ of Galvanometer.	Shunt with Core.	Deflection after 1^m.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
100	93·40	10	260°	0	139°	900	4500

If the deflection is with 1 cell = 280° and with 100 cells and a shunt of 100 = 440°, then n is $= \dfrac{59 \cdot 5 \times 440}{280} = 93 \cdot 40.$

The coefficient of temperature, or $1 \cdot 026^5$, is found in Table II. = 1·137.

Total insulation at 75° =

$$\frac{n \times v' \times \phi \times 10000}{U' \times 1 \cdot 026^t} = \frac{93 \cdot 40 \times 586 \times 260 \times 10000}{139 \times 1 \cdot 137} = 900 \text{ megohms.}$$

Total *Insulation per knot* at 75° = 900 × 5 knots = 4500 megohms.

If the calculation be made by logarithms:

$$\log. x = \log. n + \log. v' + \log. \phi + \log. 10000 - \log. 1 \cdot 137 - \log. U' + \log. 5.$$

log. 93·40	= 1·9703469	log. 1·137	= 0·0557605
log. 586·0	= 2·7678976	log. 139	= 2·1430148
log. 260	= 2·4149733		
log. 10000	= 4·0000000		2·1987753
	11·1532178		
	2·1987753		
log. 900	= 8·9544425		
log. 5	= 0·6989700		
log. 4500	= 9·6534125		

Example 2.

Length of india-rubber cable ..	=	100 knots.	
Temperature	=	70° F.	
Number of cells	=	100.	
Resistance of galvanometer ..	=	5955 Ohms.	
Shunt with cable	=	3000;	$v = 2 \cdot 985$.
Shunt with galvanometer ..	=	50;	$v' = 120 \cdot 1$.
Shunt with battery	=	80;	$v_2 = 75 \cdot 44$.

Shunt with Battery.	Constant n of Battery.	Shunt with Galvanometer.	Constant ϕ of Galvanometer.	Shunt with Cable.	Deflection after 1^m.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
80	90	50	540°	3000	412°	45·00	4500

$$x = \frac{97 \times 120 \cdot 1 \times 540 \times 10000 \times 100}{2 \cdot 985 \times 412 \times 1 \cdot 137} = 4500 \text{ megohms.}$$

Example 3.

Length of gutta-percha cable ..	=	75 knots.	
Temperature	=	60° F.	
Number of cells	=	200.	
Resistance of galvanometer ..	=	10560.	
Shunt with cable	=	1500;	$v = 8 \cdot 04$.
Shunt with galvanometer ..	=	70;	$v' = 151 \cdot 86$.
Shunt with battery	=	42;	$v_2 = 25 \cdot 24$.

Shunt with Battery.	Constant n of Battery.	Shunt with Galvanometer.	Constant ϕ of Galvanometer.	Shunt with Cable.	Deflection after 1^m.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
42	252·42	70	148°	1500	390°	6	450

$$x = \frac{252 \cdot 42 \times 151 \cdot 86 \times 148 \times 10000 \times 75}{8 \cdot 04 \times 390 \times 3 \cdot 013} = 450 \text{ megohms.}$$

Example 4.

Length of gutta-percha core = 2 knots.
Temperature .. .. .. = 75° F.
Number of cells .. .. .. = 200.
Resistance of galvanometer .. = 5620.
Shunt with core .. .. .. = 3000; $v = 2 \cdot 8733$.
Shunt with galvanometer .. = 20; $v' = 282$.
Shunt with battery .. .. = 33; $v_2 = 171 \cdot 30$.

Shunt with Battery.	Constant n of Battery.	Shunt with Galvanometer.	Constant ϕ of Galvanometer.	Shunt with Core.	Deflection after 1^m.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	8	7	8
33	171·30	20	188°	3000	252°	125	250

$$x = \frac{171 \cdot 30 \,.\, 282 \,.\, 188 \,.\, 10000 \,.\, 2}{252 \,.\, 2 \cdot 8733} = 250 \text{ megohms.}$$

D.—THE INSULATION OF A JOINT.

29. PRACTICAL EXECUTION.

For this test, in addition to the apparatus described, a well-insulated trough is used, 3 feet long, and full of water (*Fig.* 7). The joint, when it has become quite cool, and has been soaking in water for 3 hours, is, with a copper-plate P connected to an insulated copper-wire, lowered into the trough. The core on each side of the joint is then carefully dried.

The battery is of the same strength as at the insulation test, or 500 cells.

It is necessary first to test the *insulation of the trough* and leading wires by loss of charge. By connecting P to *u*, and depressing *q* for 15 seconds, the plate P is charged from Z through the key BK and the wire *x*. The plate is instantaneously discharged by releasing *q* and depressing *r*, the discharge passing through *b*, the galvanometer, and *c* to earth. The trough is again charged, kept insulated for 1 minute and discharged. If the loss of charge, when the leading wires are short, is more than 2—3 per cent., the trough is badly insulated, and its insulation must be improved.

A test should be taken to prove that all *connections* are *in order*. The joint J is connected to *k*, and when *f* is depressed, the current from Z passes through BK to the joint, which is then charged; an induced current in the water of the trough is produced, which current is taken up by the

plate P. After ½ minute, *r* is depressed, and the plate P discharged through the galvanometer to earth.

The plate P is connected to *s*, the condenser to *u*, and *q* is depressed; the joint is connected to *k*, and *f* is depressed for 1 minute, during which time the condenser becomes charged with the quantity of electricity that passes through the dielectric. At the end of 1 minute, *q* is released and *r* depressed. The charge of the condenser passes then through *b*, the galvanometer, and *c* to earth, and the amount of the charge is determined by the deflection of the galvanometer.

If the joint is then instantly discharged to earth by releasing *f*, an induced current in opposite direction to the first will be produced in the trough, and will, when P is connected to *b*, give the same deflection on the scale of the galvanometer as the first current, if all is in order.

The insulation of a joint may often be easily determined by *another method*, by connecting the battery to the insulated trough. The leakage from the charged trough through the joint into the cable can be measured by noting the deflection on the galvanometer at the discharge of the cable, after the joint has been immersed for 5 minutes.

When a defective joint, which often is the result of a flaw, is met with, Warren advises to use a *third method:* First, well clean it with water or naphtha, unless there is fear that the naphtha will conceal the defect. Connect it to an electrometer, and charge the entire joint by grasping it with the hand; then let the outer surface be freed. The operator then tests the piece of core on one side of the joint, taking care not to touch the insulator junction, by gradually wetting with a camel's-hair pencil which is in communication with

the earth. The other side is dealt with in the same way. If the electrometer shows no fall of tension, the fault is in some part of the joint; the junctions are next tested separately by passing the pencil carefully around them. Dry carefully the parts found defective, and proceed in the same way to test the joint itself; this is best done from the middle, going carefully round the core towards one of the ends or junctions. A galvanometer will serve equally well for this test, unless the loss from the joint is very small.

30. STANDARD FOR JOINTS.

No more electricity should pass in a certain time through a joint to the plate P, than would pass in the same time through a faultless core twice as long as the joint, or 6 feet long. The test ought therefore first to be made with 6 feet of faultless core and then with the joint. To simplify the test it may however be agreed that the charge received through the joint, which has been connected to the battery during 1 minute, must not be larger than say ·0005 microfarad, or $\frac{1}{1000}$ part of the charge of a condenser, the charge of which is ·5 microfarad. If the full charge of a condenser through a shunt, with a multiplying power of 2000, gives a deflection u, the charge, which the condenser has received in 1 minute through the joint, ought only to be so great that, when charged, it gives, through a shunt with a multiplying power of 2, a deflection not greater than u.

The condenser must be entirely discharged when used for testing joints, and a special condenser ought to be reserved for this use.

E.—THE POSITION AND MAGNITUDE OF A FAULT.

31. SIGNS OF FAULTS.

Larger faults, as a break in the conductor, or a hole in the dielectric, are easily discovered, as there will be obtained a smaller charge or a smaller insulation than in the faultless cable; small faults are more difficult to ascertain, but that they exist may be assumed:

When the *copper-resistance* at 75° F. is found to be lower in the cable than it was in the core;

When the *charge* diminishes;

When the *loss of charge* of the cable after 1 minute's charge and 1 minute's insulation increases, and is, for instance, at 60° F. with india-rubber more than 3 per cent., and with gutta-percha more than 15 per cent.* of the original charge;

When, at the *insulation* test, the fall of the deflection from the 1st to the 2nd minute is too small, and is for instance, at 60° F. with india-rubber less than 20 per cent., and with gutta-percha less than 4 per cent.

If the needle of the galvanometer is very unsteady during the loop test, it is likely that two faults may be found in the cable.

If a fault is small, the best plan is to enlarge it by increasing the number of cells in the battery to 100 elements in a paid-out cable, and to 1000 elements in a cable in course of

* See L. Clark and R. Sabine: 'Electrical Tables and Formulæ,' 1871, p. 121.

manufacture, changing the current, for instance, every 5th minute, until the fault is perfectly broken down.

When the zinc-pole is connected with the cable, the conductor will be coated with hydrogen and the iron wires with oxygen, and this polarization will create a current in the cable so that the cable disconnected from the battery will give a deflection on the galvanometer-scale, say to the right. If the copper-pole is connected with the cable, the hydrogen on the conductor will be reduced and replaced by oxygen, while the iron wires will be coated with hydrogen, and the cable current will give a deflection in the opposite direction, or to the left. There is a moment when these opposite actions of the hydrogen and the oxygen are apparently balanced, where the end of the wire is unpolarized and probably uncoated, and then only can its correct resistance be determined. The test is then quickly made, alternately with negative and positive currents, the mean of which is taken.

As the current, when the copper-pole is connected to the cable, oxidizes the exposed conductor, the insulation of the cable is apparently improved, but at the same time some of the conductor is consumed. To preserve a cable it is therefore better to have the zinc-pole connected to the cable.

When the zinc-pole is connected with a broken cable, its copper-resistance ought to diminish as the conductor is de-oxidized; but if it does not diminish at first this may arise from the formation of hydrogen bubbles on the conductor, which increase its resistance, and the current must then be kept on until the resistance decreases and finally remains almost unchanged. It is well in a broken cable to

connect the zinc-pole to the conductor for a certain time, say 12 hours, and then change the current every 5th minute.

As the strength of the cable-current may be equal to that of about one Daniell's cell, the larger the number of cells used in testing the less this cable-current will influence the result. Sometimes however it is advisable to use small battery-power, to diminish the polarization and render the measurement steadier.

The proper resistance of the fault will often be equal to the resistance of two or three miles of core, so that the real distance to the fault is two or three miles less than that shown by the test.

32. TESTS FROM BOTH ENDS OF THE CABLE.

The test can be taken from both ends of the cable, when in course of manufacture, or when the fault is so small that it is possible to work through the cable, or when there are two telegraph lines between the two stations. This test, termed the *loop test*, is independent of the resistance in the fault, and should be used whenever possible.

The cable in which there is a fault at p, *Fig.* 8, is connected with its ends to m and n in such a way, that the fault is nearer to m, and thus nearer to the resistance-coil R, it being impossible to establish equilibrium unless this condition is fulfilled.

The earth wire, which is generally connected to the point m of the Wheatstone bridge, is removed, as the current here passes to earth through the fault.

The battery should contain as many cells as possible.

Ratio of balance should be made equal to 1, viz.: 1000 : 1000 or 100 : 100.

The copper-resistance R in the faultless cable is supposed to be known from earlier tests; the length of the cable is l. When the fault has shown itself, the resistance of the greater length $n\,p$ is put $= y$, the resistance of the smaller length $m\,p = z$, and the resistance of the fault $= q$. The resistance R has now to be decreased to R_1 to cause the needle of the galvanometer to remain at zero.

Then:

$$y + z = R$$

and
$$y + q = R_1 + z + q, \text{ or } y = R_1 + z.$$

Consequently:

$$z = \frac{R - R_1}{2}$$

The distance x of the fault from m is found from the equation.

$$\frac{R}{z} = \frac{l}{x}, \text{ or } x = \frac{z\,l}{R}.$$

Example.

Length of the cable = 120 knots.
R = 500 Ohms.
R_1 = 160 Ohms.

Then:

$$y + z = 500, \text{ and } y = 160 + z.$$

Consequently:

$$z = 170, \text{ and } x = \frac{170 \times 120}{500}\ 40 \cdot 8 \text{ knots.}$$

By connecting the points m and l, and removing the earth wire from the key BK the circuit is closed metallically through the cable, and in this way the original copper-resistance R may be determined independent of the fault.

The test may be taken from both ends by *another method:*

Insulate at the two ends alternately for 5 minutes, while the copper-resistance is taken at the other end with negative and positive current, alternately, as quickly as possible. The cable is insulated at m, and the resistance found by testing from the end n is:

$$R_1 = y \times q;$$

when the cable is insulated at n, the resistance found by testing from the end m is:

$$R_2 = z + q.$$

As $R = y + z$, these three equations give:

$$R_1 - R_2 = y - z, \text{ and}$$

$$y = \frac{R + R_1 - R_2}{2}.$$

A resistance should be inserted at the end nearest the fault, so that the fault is placed in the centre of the circuit and the same results approximately obtained from both ends. If the earth-current is weak or constant, it may be advisable first to try to determine the position of the fault by a *third method,* without employing a battery. The cable is insulated at the end m, Fig. 8, and put to earth at n through a galvanometer, properly shunted, the current through the fault at p in the cable giving a deflection u. A resistance

R_2 is put in circuit until the deflection $u/_2$ is obtained, then $R_2 = y + q$, as the resistance of the galvanometer and the shunt may be neglected. In the same way, from the end m

is found: $R_3 = z + q$;

which with $R_2 = y + q$

gives: $R_2 - R_3 = y - z$.

We then have: $R = y + z$, and

we find: $R_2 - R_3 + R = 2y$, or

$$y = \frac{R_2 - R_3 + R}{2}.$$

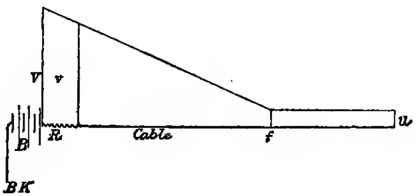
A *fourth method* of finding the copper-resistance consists in connecting both ends of the cable to earth through the galvanometer at the two end stations, where the deflections u and u' are read. If the length of the cable is $= l$, and the resistance of the fault be not taken into consideration, then the fault is at a distance $= \frac{u}{u + u'} \times l$ from the one end, and $\frac{u'}{u + u'} \times l$ from the other end. If the resistances R and R_1 are inserted between the galvanometer and the earth until there are obtained deflections only half those previously observed, then $R + R_1$ gives the resistance of the cable + twice the resistance of the fault.

In the *potential method* for finding faults, Thomson's Quadrant Electrometer is very often used, but an ordinary galvanometer with a condenser may be employed. The observations are taken simultaneously at both ends of the cable. To compare the deflections of the galvanometer at the two end stations, it is advisable to charge with a standard electro-

motive force, such as L. Clark's Standard Cell, a standard condenser, say of $^1/_3$ microfarad, and to read the deflection, when the condenser is at both stations discharged through the galvanometer; if the galvanometer at A gives 300°, while the galvanometer at B gives only 200 degress, then 1° at A has to be put equal to $^2/_3$° at B.

The cable, with a fault at *f*, *Fig.* 9*a*, is at one end connected to a battery and resistance-coil R, its other end being

FIG. 9*a*.



insulated at the distant station at *u*. A current from a battery with the key BK is kept flowing through the resistance R and the cable. If there is only one fault, the potential of the line will fall gradually towards the fault, and be the same at the other end of the cable as at the fault. Consequently, if the potentials at V and *v* are measured, and the electrician at the other end measures the potential at *u*, that is, the same as at the fault *f*, sufficient data are obtained to determine the position of the fault.

The arm *q* of the key DK, *Fig.* 9*b*, is depressed, and making contact at *s*, charges the condenser to the potential of the point V; after 15 seconds the condenser is discharged through the shunted galvanometer by releasing *q* and depressing *r*. This deflection having been noted, the potential

at the point v is next ascertained in the same manner as that at V. Meanwhile the potential at u has been determined by similar operations, the end u having been connected to a condenser simultaneously, or as near as possible simultaneously, with the operations at the other end. We then have:

$$\frac{V - v}{R} = \frac{v - u}{x};\ x = R\,\frac{v - u}{V - v}.$$

33. TESTS FROM ONE END OF THE CABLE.

a. By Copper-resistance.

Where there is good connection to earth at the fault, and the cable is broken, the copper-resistance in the length $n\,p$, Fig. 8, is measured. Should this resistance be $= r$, whilst the resistance in the whole cable, which has a length l, is previously found, when the cable is perfect $=$ R, then the length $n\ p$ is $= \frac{r \times l}{R}$.

The copper-resistance may also be found by leading the current from two or more cells through the galvanometer with a shunt of small resistance, say 100 feet of leading wire, into the cable. Alternately positive and negative currents are employed, and the mean reading is taken. Instead of the cable, a resistance is then put in circuit, until the same deflection is obtained, and this resistance is the copper-resistance of the cable.

The following applies to a *broken cable:*

Mr. Kennelly has proved experimentally that, when the strength of the testing current does not exceed 25 milli-

ampères, *the resistance of the exposed copper wire varies inversely as the square root of the current.*

By measuring the copper resistance with two different, but known, battery powers alternately with positive and negative currents, or by balancing the resistance to the "false zero" (see page 8), we obtain one value (R) say with c cells, and another value (R_1) say with c_1 cells, both representing the resistance of the cable up to the break plus the resistance of the break itself.

In accordance with Kennelly's law, as quoted above, we arrive at the following expression for the true resistance r of the cable up to the break (i.e. with the resistance of the latter eliminated), viz:

$$r = \frac{R\sqrt{c} - R_1\sqrt{c_1}}{\sqrt{c} - \sqrt{c_1}}$$

For example, when $R = 1500^{\omega}$, $R_1 = 1600^{\omega}$, $c = 25$ and $c_1 = 9$, then the true resistance r, up to the break, is determined by:

$$r = \frac{1500\sqrt{25} - 1600\sqrt{9}}{\sqrt{25} - \sqrt{9}} = 1350^{\omega}.$$

Sir Henry Mance eliminates the polarization current and the earth current by applying one current only instead of reversing the battery, and by varying the ratio of balance, so that two readings are obtained, one with the ratio 1000:1000, and another with 100 : 100. The Wheatstone bridge is to be manipulated in the following manner:—Two readings are taken with the same current, as rapidly as possible after each other, the testing battery not to be disconnected or reversed during the two observations. Let the reading

obtained with the $\frac{100}{100}$ proportion coils be $= R_1$, and the reading obtained with the $\frac{1000}{1000}$ proportion coils be $= R_2$; let the resistance of *one* of the smaller proportion coils of 100 be $= P_1$, and the resistance of *one* of the larger proportion coils of 1000 be $= P_2$; then the true resistance of the cable tested up to and *through* the break is:

$$r = \frac{R_1 P_2 - R_2 \cdot P_1}{P_2 + R_2 - P_1 - R_1}.$$

In this formula, which is derived from Kirchhoff's laws, no notice is taken of the internal resistance of the battery. If the resistance of the battery be called r' the formula reads as follows:

$$r = \frac{R_1 (2 r^1 + P_2) - R_2 (2 r^1 + P_1)}{R_2 + P_2 - P_1 - R_1}.$$

To ascertain whether the cable is broken asunder or not, reversals should be sent from the one end, while at the other the mirror galvanometer is observed. If reversals appear at the other end, the cable is only faulty, whereas it is broken in two, if no reversals are visible.

b. By Blavier's Method.

This method is used when, as generally happens, there is not good connection to earth at the fault, and the cable is not broken. To determine the position of the fault with all accuracy possible, it is advisable to enlarge it by charging the cable for some time with changing currents from a strong battery.

When this test is taken it is well to have the other end of the cable alternately insulated and put to earth for 5 minutes, and to endeavour to obtain a reading with zinc and copper-currents alternately with as short intervals as possible.

The copper-resistance in the faultless cable is = R; the resistance in the faulty cable insulated at the end m is $= R_1$; and the resistance of the cable with fault and with the end m connected to earth is $= R_2$.

The resistances in the lengths $n\,p$ and $m\,p$ and in the fault are as before $= y, z,$ and q.

Then there is given:

$$R = y + z$$
$$R_1 = y + q$$
$$R_2 = y + \frac{z\,q}{z+q}, \text{ where } \frac{z\,q}{z+q} \text{ is the total resistance in } z \text{ and } q.$$

There is found:

$$R - z = R_1 - q, \text{ or } q = R_1 - R + z$$

$$R - z = y = R_2 - \frac{z\,q}{z+q}, \text{ or } R - z = R_2 - \frac{z\,(R_1 - R + z)}{R_1 - R + 2\,z}.$$

Both sides of the equation multiplied by $R_1 - R + 2\,z$ give:

$$z^2 + 2\,(R_2 - R)\,z = -R^2 - R_1\,R_2 + R\,R_1 + R\,R_2$$
$$z = R - R_2 + \sqrt{R_2^2 - R_1\,R_2 + R\,R_1 - R\,R_2}$$
$$y = R - z = R_2 - \sqrt{R_2^2 - R_1\,R_2 + R\,R_1 - R\,R_2}$$
$$y = R_2 - \sqrt{(R - R_2)\,(R_1 - R_2)}.$$

The resistance in $n\,p$ being thus determined, the position of the fault is found as before.

EXAMPLE.

Length of the cable = 120 knots.
$R = 500$ Ohms.
$R_1 = 400$ Ohms.
$R_2 = 379$ Ohms.

Then let there be found:

$$z = 160, \text{ and } y = 340.$$

Thus the length $n\,p$ is $= \dfrac{340 \times 120}{500} \doteq 81{\cdot}6$ knots.

c. Test by Charge.

If the fault is caused by a break in the copper wire, whilst the dielectric is quite sound, or when it is possible, in a broken cable, to seal the exposed copper wire to a comparative state of insulation, the position of the fault is found by charging the cable from one end, determining the amount of the charge, and dividing this by the known charge per knot.

When an earth or polarization current is flowing, it will, according to its direction, either increase or decrease the apparent discharge from the cable. To eliminate this effect, the throw of the galvanometer needle, caused by this current, should be observed, and the *deflection due to the discharge only* calculated by the following formula, viz.:

$$x = \sqrt{U\,(U - u)};$$

where U is the deflection (the throw of the needle) of the discharge and the polarization current, and u the deflection due to the polarization current only.

The above formula is based upon Mr. Hockin's investigations, and is found of great value in practice.

TESTING DURING THE LAYING OF A CABLE.

34. ELECTRICAL ARRANGEMENT ON SHIP AND ON SHORE.

1. When *on ship* (*Fig.* 10) f is depressed, the current passes from h through k, b and the testing screw T of the commutator into the cable connected to the screw C, and insulated in a commutator at its other end on shore. By opening the short-circuit key SK, the current passes through the shunted galvanometer, and a deflection is obtained.

Regular fall of the deflection indicates good condition of the cable; with decrease of insulation the deflection will increase.

By disconnecting T from, and connecting S to, the cable, the ship is put in circuit for speaking.

2. *On shore* (*Fig.* 11) the cable is connected to a commutator, and a clock causes, every tenth minute, the arm $p\ q$ to touch for some few seconds the button r, charging the condenser and at the same time giving a throw on the ship galvanometer; when the arm $p\ q$ again touches the button t, the condenser is discharged through the shore galvanometer. Instead of a commutator, an ordinary charge and discharge key may be used, worked by hand.

If the insulation is decreasing the discharge becomes smaller, and in the event of loss of continuity, or a total loss of insulation, neither charge of the condenser nor discharge will be obtained.

The ends of the cable must always be kept dry and paraffined.

If the cable is permanently connected through a very *high resistance* R_2 and a galvanometer G_2 to earth, ship is able to signal at any time to shore by either reversal or reduced tension, and shore obtains by this arrangement a permanent insulation and continuity test. For this resistance a bar of selenium, or a plumbago line on glass may be used, and a suitable shunt may be used to make the deflection on the galvanometer scale about 200 divisions.

3. Both ship and shore must be provided with a complete set of testing apparatus, always kept ready for testing at any moment.

35. INSTRUCTIONS FOR TESTING ON SHIP AND ON SHORE.

1. *On ship,* the cable being connected to galvanometer for insulation test, the deflection is read every minute and noted down.

The resistance of the battery and the constant of the galvanometer being determined, the insulation readings for every 10 minutes are reduced in the ordinary way to megohms per knot.

2. Ship must note the time when the continuity-throws from shore occur, which will be about every tenth minute.

3. Ship will reverse the current every hour, when the discharge-throws on shore will also be reversed.

4. Ship will reverse the current 10 minutes before noon, and shore will acknowledge this by pressing in the stud *s* three times and bringing the arm $p\ q$ in contact with r,

giving three kicks on the ship galvanometer. Ship then releases T and depresses S, and shore having on its commutator released T′ and depressed S′, all will be in readiness for speaking. Ship then gives shore the time by sending dots, stopping at exactly twelve o'clock Greenwich time. Ship sends any necessary information, as distance run and miles paid out, as quickly as possible, always finishing by "insulate," which shore station will immediately obey, both stations releasing S and S′ and depressing T and T′, and being again ready for the insulation-test.

5. Ship not to send any communications except those ordered by the chief electricians and engineers.

6. *On shore*, the condenser in every tenth minute, commencing at the full hour, connected through the arm $p\ q$ and the button r of the commutator for 10 seconds to the cable, the charge abstracted from the cable producing a throw on the deflection-scale on board; the condenser is instantly afterwards discharged through the shunted galvanometer G′ by the falling back of the arm $p\ q$ to the button t. To render this reading accurate, it is important to make it as high as possible. Shore must multiply these readings by the value of the shunt, and enter the true value of each reading.

7. At reversals at the full hour, except at noon, shore will not alter any connections, but simply note time and amount of throw on the galvanometer G′; but if reversals are not at the hour, shore will depress the stud s three times and join up for speaking, ready to receive messages from ship.

8. Shore to make no communication whatever, or ask any questions, except in reply to demands from ship. All information demanded to be given with as few words as possible.

9. Shore to keep a diary, in which the names of the electrician in charge and the clerk on duty are entered, so that the responsible party for any time can be found. In the diary all observations must be recorded in full, and timed.

10. The testing-room on shore must be kept strictly private, and no one admitted except on business.

11. Should any loss of insulation or any *fault* occur, and ship, having carefully examined all connections, has found that the extra loss of current is due to the cable, the current is reversed, as a signal to shore to join up for receiving messages, and if speaking is possible ship may, for instance, direct shore to remove end of cable from the commutator, carefully retrim and insulate it, that ship may take insulation-test.

Should the fault make speaking impossible, ship and shore will proceed as follows:—

Shore having joined up for speaking until the next full 10 minutes, insulates for 10 minutes, puts to earth for 10 minutes, and continues to insulate and put to earth alternately every 10 minutes until the next full hour. Shore then again joins up 10 minutes for speaking, and commences again to insulate and put to earth alternately every 10 minutes until the next full hour, and so on until signal is received from ship. If a fault in the instruments makes speaking impossible, at every full hour ship and shore join up for speaking for 10 minutes, but always insulate again until the next full hour.

12. From the day communication with the ship ceases, shore will have daily to take two series of tests, each of twelve readings for copper-resistance, six with zinc to cable,

and six with copper to cable, alternately. One series of these tests to be taken at 9 A.M., and the other at 6 P.M.

13. *Records* of the tests made and results obtained are to be carefully kept, both on ship and shore.

14. The chief electrician has to ascertain before starting that all *instruments* are *in good order* and all connections properly made, as well on shore as on board ship.

15. The above regulations can only be modified by order from the ship. The strictest fulfilment is of the utmost urgency, and no excuse whatever for any neglect will be accepted.

FORMULÆ.

36. FORMULÆ FOR THE CHARGE OF CORES.

The charge C per knot of a core is determined by the following equation:

$$C = c \frac{E \cdot l}{R \log. \frac{D}{d}},$$

where c is a constant, E the electro-motive force of the battery, l the length in knots of the core, R the resistance per knot of the insulator, D the diameter of the core, and d the diameter of the conductor.

If for Hooper's core, the following numbers are given:

$$C = \cdot 45,\ R = 4000,\ D = \cdot 318'',\ d = \cdot 145'',\ \text{and if } E \text{ is } = 1, \text{ and } l = 1, \text{ then } c \text{ is } = 614.$$

The charge C per knot is then

$$= \frac{614}{4000 \log. \frac{D}{d}} = \frac{\cdot 1535}{\log. \frac{D}{d}} \text{ microfarads.}$$

The charge C per knot with ordinary gutta-percha core is

$$= \frac{\cdot 1877}{\log. \frac{D}{d}} \text{ microfarads.}$$

The charge C per knot with Willoughby Smith's gutta-percha core is found to be

$$= \frac{\cdot 15163}{\log. \frac{D}{d}} \text{ microfarads.}$$

EXAMPLE.—When $d = \cdot 145''$ and $D = \cdot 318$, the capacity is :

With Hooper's core	=	·45
With ordinary gutta-percha core	=	·55
With Willoughby Smith's gutta-percha core	=	·44

37. FORMULÆ FOR THE INSULATION OF CORES.

The insulation per knot at 75° F. is :

With Hooper's core	$= 1\cdot 3 \times \log. \frac{D}{d}$	megohms.
With ordinary gutta-percha core	$= \cdot 077 \times \log. \frac{D}{d}$	"
With Willoughby Smith's core	$= \cdot 035 \times \log. \frac{D}{d}$	"

where D is the diameter of the core, and d the diameter of the conductor, and where the first four figures of the logarithm are regarded as a whole number.

The insulation per knot at 75° F. of a core with a strand conductor, calculated *by weights*, and not by diameters, is :

For Hooper's core	$= 1 \cdot 3 \times \log.\sqrt{1 + 5 \cdot 7 \frac{W}{w}}$
For ordinary gutta-percha core	$= \cdot 077 \times \log.\sqrt{1 + 6 \cdot 9 \frac{W}{w}}$
For Willoughby Smith's gutta-percha core ..	$= \cdot 035 \times \log.\sqrt{1 + 6 \cdot 9 \frac{W}{w}}$

where W is the weight of the dielectric and w the weight of the conductor, and where the first four figures of the logarithm are regarded as a whole number.

EXAMPLE.—When $d = \cdot 113$ and $D = \cdot 291$, the insulation is :

With Hooper's core	= 5340 megohms.
With ordinary gutta-percha core	= 316 „
With Willoughby Smith's gutta-percha core	= 144 „

When u = 180 lbs. and W = 180 lbs., then the insulation is :

With Hooper's core	= 5340 megohms.
With ordinary gutta-percha core	= 345 „
With Willoughby Smith's gutta-percha core	= 157 „

38. FORMULÆ FOR THE SPEED IN CABLES.

The *speed* of working a cable is proportionate to:

$$\frac{S}{l^2 \times C}, \text{ or } \frac{1}{l^2 \times C \times r},$$

where S is the specific conductivity of the copper, l the length of the cable, C the charge of the cable per knot, and r the resistance of the copper per knot.

When the holes in the machine, in which the copper wires are drawn, are worn out, the diameter of the wires, and consequently their conductivity will increase, and the speed of the cable would also increase, if the charge did not generally increase at the same time, by which the speed will be again diminished.

When it is fixed that the specific conductivity S shall be not less than 90 per cent., and the charge C not more than ·44 microfarad, then the speed through 1 knot of cable will be proportionate to $\frac{90}{\cdot 44} = 205$; and the charge may increase to ·45 and ·46 microfarad, without the speed being altered, if the conductivity of the copper at the same time increases to 93·25 and 94·30, because $\frac{93 \cdot 25}{\cdot 45} = \frac{94 \cdot 30}{\cdot 46} = 205$.

As the charge of the core is inversely proportionate to $\log. \frac{D}{d}$, and the resistance of the copper is inversely proportionate to d^2, where D is the diameter of the core in mils. (or thousandths of an inch), and d the diameter of the conductor in mils., the working *speed* can *also* be *expressed by:*

$$\text{constant} \times \frac{d^2 (\log. D - \log. d)}{l^2}.$$

The speed or number of words per minute is :—

For Hooper's core, with Morse apparatus :

$$700 \frac{d^2 (\log. D - \log. d)}{l^2};$$

for Hooper's core, with reflecting galvanometer :

$$7700 \frac{d^2 (\log. D - \log. d)}{l^2};$$

for Willoughby Smith's core, with Morse apparatus :

$$625 \frac{d^2 (\log. D - \log. d)}{l^2};$$

for Willoughby Smith's core, with reflecting galvanometer :

$$6250 \frac{d^2 (\log. D - \log. d)}{l^2};$$

for gutta-percha core, with Morse apparatus :

$$530 \frac{d^2 (\log. D - \log. d)}{l^2};$$

for gutta-percha core, with reflecting galvanometer :

$$5830 \frac{d^2 (\log. D - \log. d)}{l^2}.$$

The obtained maximum speed is 50 per cent. higher than the above working speed.

Example 1.—A Hooper's core, of 300 lbs. copper and 200 lbs. india-rubber, or with $d = \cdot 145''$ and $D = \cdot 318''$, will, for a distance of 900 nautical miles, give a speed with Morse apparatus :

$$700 \frac{145^2 (\log. 318 - \log. 145)}{900^2} = 6 \cdot 2 \text{ words per minute.}$$

The maximum speed will be about 9 words per minute.

With a reflecting or mirror galvanometer, the speed will be $11 \times 6 \cdot 2 = 68$ words per minute.

EXAMPLE 2.—A Hooper's core, of 180 lbs. copper and 180 lbs. india-rubber, or with $d = \cdot 110''$ and $D = \cdot 290''$, will, for a distance of 350 nautical miles, give a speed with Morse apparatus:

$$700 \frac{110^2 (\log. 290 - \log. 110)}{350^2} = 29 \text{ words per minute.}$$

EXAMPLE 3.—A core of 200 lbs. copper and 200 lbs. gutta-percha, or with $d = \cdot 119''$ and $D = \cdot 335''$, will, for a distance of 400 nautical miles, give a speed with Morse apparatus:

$$530 \frac{119^2 (\log. 335 - \log. 119)}{400^2} = 21 \text{ words per minute.}$$

EXAMPLE 4.—A core of 300 lbs. copper and 400 lbs. gutta-percha, or with $= d \cdot 147''$ and $D = \cdot 467''$, will, for a distance of 1857 nautical miles, as for the Atlantic Cable of 1866, give a speed with a reflecting galvanometer, or the mirror system of

$$5830 \frac{147^2 (\log. 467 - \log. 147)}{1857^2} = 18 \cdot 3 \text{ words per minute.}$$

The maximum speed obtained on this cable is 25 words per minute.

Robert Sabine has found that *the time* required *for a signal* to become recognizable through a line is:

With a Morse apparatus .. $t = \frac{414}{10^9} C\,r$ seconds.

„ Hugh's instrument .. $t = \frac{105}{10^9} C\,r$ „

„ Mirror galvanometer $t = \frac{47}{10^9} C\,r$ „

where C is the capacity of the line in microfarads, and r the copper-resistance in Ohms. The formulæ show that the speed depends on the inertia of the apparatus, and on the retardation of the cable.

EXAMPLE.—If a core with 200 lbs. copper and 200 lbs. gutta-percha has a capacity = 0·40 per knot, and a copper-resistance of 6·25 per knot, or for a line of 400 knots C = 160, and r = 2500, then with a Morse apparatus:

$$t = \frac{414}{10^9} \cdot 160 \cdot 2500 = c \cdot \tfrac{1}{6} \text{ second, or}$$

360 signs per minute.

The speed of such a cable has been found to be 21 words per minute, but as an average word consists of 5 letters and each letter of about 4 signs, the 21 words give:

$$21 \times 5 \times 4 = 420 \text{ signs.}$$

39. FORMULÆ FOR THE WEIGHTS OF CONDUCTOR AND INSULATOR.

The weight per knot of a copper wire is $= \frac{d^2}{55}$ lbs., where d is the diameter of the wire in mils. (thousandths of an inch).

The weight per knot of a copper strand is $= \frac{d^2}{70 \cdot 4}$ lbs.

The weight per knot of india-rubber is $= \frac{D^2 - d^2}{401}$ lbs., where D is the diameter of the core, and d the diameter of the conductor in mils.

The weight per knot of gutta-percha is $= \dfrac{D^2 - d^2}{491}$.

EXAMPLE.—A gutta-percha core is required, which has the same charge and the same weight of copper as an india-rubber core with the weight per knot of 300 lbs. copper and 200 lbs. india-rubber. What is the weight of gutta-percha per knot?

The charge of the india-rubber core is found to be = ·45 microfarad.

Then:

$$\cdot 45 = \frac{\cdot 18769}{\log. \dfrac{D}{\cdot 145}}; \ \log. \frac{D}{\cdot 145} = \cdot 417; \ D = \cdot 379'';$$

$$300 = \frac{d^2}{55}; \ d = \cdot 145''.$$

The weight of gutta-percha is:

$$\frac{D^2 - d^2}{491} = \frac{\cdot 379^2 - \cdot 145^2}{491} = 250 \text{ lbs.}$$

40. FORMULÆ FOR THE DIAMETERS OF CORES.

The outer diameter D in mils. of a gutta-percha core, of which the strand conductor weighs c lbs., and the gutta-percha g lbs. per knot, is:

$$D = \sqrt{c \times 70\cdot 4 + g \times 491.}$$

The outer diameter D in mils. of an india-rubber core, of which the conductor weighs c lbs. and the india-rubber i lbs. per knot, is:

$$D = \sqrt{c \times 70\cdot 4 + i \times 401.}$$

EXAMPLE.—If in a gutta-percha core the copper strand weighs 200 lbs. and the gutta-percha 200 lbs. per knot, then:

$$d = \sqrt{200 \times 70 \cdot 4} = 119, \text{ and}$$
$$D = \sqrt{200 \times 70 \cdot 4 + 200 \times 491} = 335.$$

When the dielectric has the same weight as the conductor, or when $w = W$, then:

$$\frac{D}{d} = \frac{\sqrt{w \times 70 \cdot 4 + W \times 491}}{\sqrt{w \times 70 \cdot 4}} = \sqrt{1 + 6 \cdot 9744 \frac{W}{w}} = 2 \cdot 82.$$
$$D = 2 \cdot 82 \times d = 2 \cdot 82 \,.\, 119 = 335.$$

41. FORMULÆ FOR THE DIAMETERS OF CABLES.

The *outer diameter* D of a bright iron cable (a cable without external covering to the iron wires) with n wires, each wire with a diameter d, is:

$$D = d \,.\, \frac{1 + \sin. \frac{180}{n}}{\sin. \frac{180}{n}}.$$

The *inner diameter* D′ of the iron sheathing is:

$$D' = d \,.\, \frac{1 - \sin. \frac{180}{n}}{\sin. \frac{180}{n}}.$$

EXAMPLE.—For a cable with 12 wires, No. 8, each with a diameter of $\cdot 165''$:

$$D = \cdot 165'' \times \frac{1 + \sin. 15^\circ}{\sin. 15^\circ} = \cdot 165 \frac{1 + \cdot 258819}{\cdot 258819} = \cdot 802''$$
$$D'' = \cdot 165'' \times \frac{1 - \cdot 258819}{\cdot 258819} = \cdot 472''.$$

TABLE I.

TEMPERATURE COEFFICIENTS FOR CALCULATING THE RESISTANCE OF COPPER AT 75° F.

Temperature lower than 75°.	Coefficient.	Logarithm of Coefficient.	Temperature higher than 75°.	Coefficient.	Logarithm of Coefficient.
0	1·0000	·0000000	0	1·0000	·0000000
1	1·0021	·0009111	1	·9979	·9990870–1
2	1·0042	·0018202	2	·9958	·9981721–1
3	1·0063	·0027275	3	·9937	·9972553–1
4	1·0084	·0036328	4	·9916	·9963365–1
5	1·0105	·0045363	5	·9896	·9954597–1
6	1·0127	·0054808	6	·9875	·9945371–1
7	1·0148	·0063805	7	·9854	·9936126–1
8	1·0169	·0072782	8	·9834	·9927302–1
9	1·0191	·0082168	9	·9813	·9918018–1
10	1·0212	·0091108	10	·9792	·9908714–1
11	1·0233	·0100030	11	·9772	·9899835–1
12	1·0255	·0109357	12	·9751	·9890492–1
13	1·0276	·0118241	13	·9731	·9881575–1
14	1·0298	·0127529	14	·9711	·9872640–1
15	1·0320	·0136797	15	·9690	·9863238–1
16	1·0341	·0145625	16	·9670	·9854265–1
17	1·0363	·0154855	17	·9650	·9845273–1
18	1·0385	·0164065	18	·9629	·9835812–1
19	1·0407	·0173256	19	·9609	·9826782–1
20	1·0428	·0182010	20	·9589	·9817733–1
21	1·0450	·0191163	21	·9569	·9808666–1
22	1·0472	·0200296	22	·9549	·9799579–1
23	1·0494	·0209411	23	·9529	·9790473–1
24	1·0516	·0218506	24	·9509	·9781348–1
25	1·0538	·0227582	25	·9489	·9772204–1
26	1·0561	·0237050	26	·9469	·9763041–1
27	1·0583	·0246088	27	·9449	·9753858–1
28	1·0605	·0255107	28	·9429	·9744656–1
29	1·0627	·0264107	29	·9409	·9735435–1
30	1·0650	·0273496	30	·9390	·9726656–1
31	1·0671	·0282051	31	·9369	·9716932–1
32	1·0692	·0290590	32	·9348	·9707187–1
33	1·0713	·0299111	33	·9327	·9697420–1
34	1·0734	·0307616	34	·9306	·9687630–1
35	1·0755	·0316104	35	·9285	·9677819–1
36	1·0777	·0324979	36	·9264	·9667985–1
37	1·0798	·0333433	37	·9243	·9658130–1
38	1·0819	·0341871	38	·9222	·9648251–1
39	1·0841	·0350693	39	·9201	·9638350–1
40	1·0862	·0359098	40	·9180	·9628427–1

TABLE II.

TEMPERATURE COEFFICIENTS FOR CALCULATING THE DI-ELECTRIC RESISTANCE OF HOOPER'S INDIA-RUBBER AT 75° F.

Difference in Temperature, t.	$1{\cdot}026\ t$.	t Log. $1{\cdot}026$.	Difference in Temperature, t.	$1{\cdot}026\ t$.	t Log. $1{\cdot}026$
0	1·000	·00000	21	1·715	·23415
1	1·026	·01115	22	1·759	·24530
2	1·053	·02230	23	1·805	·25645
3	1·080	·03345	24	1·852	·26760
4	1·108	·04460	25	1·900	·27875
5	1·137	·05575	26	1·949	·28990
6	1·167	·06690	27	2·000	·30105
7	1·197	·07805	28	2·052	·31220
8	1·228	·08920	29	2·105	·32335
9	1·260	·10035	30	2·160	·33450
10	1·293	·11150	31	2·216	·34565
11	1·326	·12265	32	2·274	·35680
12	1·361	·13380	33	2·333	·36795
13	1·396	·14495	34	2·394	·37910
14	1·443	·15610	35	2·456	·39025
15	1·470	·16725	36	2·520	·40140
16	1·508	·17840	37	2·586	·41255
17	1·547	·18955	38	2·653	·42370
18	1·587	·20070	39	2·722	·43485
19	1·629	·21185	40	2·793	·44600
20	1·671	·22300			

TABLE III.

TEMPERATURE COEFFICIENTS FOR CALULATING THE DIELECTRIC RESISTANCE OF ORDINARY GUTTA-PERCHA AT 75° F.

Temperature Fahr.	Resistance.	Log. Resistance.	Temperature Fahr.	Resistance.	Log. Resistance.
32°	23·622	1·373317	67°	1·801	·255514
33	21·947	1·341375	68	1·673	·223496
34	20·391	1·309439	69	1·555	·191730
35	18·945	1·277495	70	1·444	·159567
36	17·602	1·245562	71	1·342	·127753
37	16·354	1·213624	72	1·247	·095867
38	15·195	1·181701	73	1·158	·063709
39	14·117	1·149742	74	1·076	·031812
40	13·116	1·117801	75	1·000	·000000
41	12·186	1·085861	76	·9418	·973959
42	11·322	1·053923	77	·8870	·947924
43	10·520	1·022016	78	·8354	·921895
44	9·774	·990072	79	·7867	·895809
45	9·081	·958134	80	·7410	·869818
46	8·437	·926188	81	·6978	·843731
47	7·839	·894261	82	·6572	·817698
48	7·283	·862310	83	·6190	·791691
49	6·767	·830396	84	·5829	·765594
50	6·287	·798444	85	·5490	·739572
51	5·841	·766487	86	·5171	·713575
52	5·427	·734560	87	·4870	·687529
53	5·042	·702603	88	·4586	·661434
54	4·685	·670710	89	·4319	·635383
55	4·353	·638789	90	·4068	·609381
56	4·044	·606811	91	·3831	·583312
57	3·757	·574841	92	·3608	·557267
58	3·491	·542950	93	·3398	·531223
59	3·244	·511081	94	·3200	·505150
60	3·013	·478999	95	·3014	·479143
61	2·800	·447158	96	·2839	·453165
62	2·601	·415140	97	·2674	·427161
63	2·417	·383277	98	·2518	·401056
64	2·245	·351216	99	·2371	·374932
65	2·086	·319314	100	·2233	·348889
66	1·938	·287354			

TABLE IV.

TEMPERATURE COEFFICIENTS FOR CALCULATING THE DIELECTRIC RESISTANCE OF WILLOUGHBY SMITH'S GUTTA-PERCHA AT 75° F.

Temperature Fahr.	Resistance.	Log. Resistance.	Temperature Fahr.	Resistance.	Log. Resistance.
32°	27·913	1·445807	67°	1·858	·269046
33	25·834	1·412192	68	1·719	·235276
34	23·910	1·378580	69	1·591	·201670
35	22·128	1·344942	70	1·473	·168203
36	20·480	1·311330	71	1·363	·134496
37	18·954	1·277701	72	1·261	·100715
38	17·542	1·244079	73	1·167	·067071
39	16·235	1·210452	74	1·080	·033424
40	15·025	1·176815	75	1·000	·000000
41	13·906	1·143202	76	·9375	·971971
42	12·870	1·109579	77	·8789	·943940
43	11·911	1·075948	78	·8240	·915927
44	11·024	1·042339	79	·7725	·887899
45	10·203	1·008728	80	·7242	·859859
46	9·442	·975064	81	·6789	·831806
47	8·739	·941462	82	·6365	·803798
48	8·088	·907841	83	·5967	·775756
49	7·485	·874192	84	·5594	·747723
50	6·928	·840608	85	·5245	·719746
51	6·412	·806994	86	·4917	·691700
52	5·934	·773348	87	·4609	·663607
53	5·492	·739731	88	·4321	·635584
54	5·083	·706120	89	·4051	·607562
55	4·704	·672467	90	·3798	·579555
56	4·354	·638888	91	·3561	·551572
57	4·029	·605197	92	·3338	·523486
58	3·729	·571592	93	·3130	·495544
59	3·451	·537945	94	·2934	·467460
60	3·194	·504335	95	·2751	·439491
61	2·956	·470704	96	·2579	·411451
62	2·736	·437116	97	·2417	·383277
63	2·532	·403464	98	·2266	·355260
64	2·343	·369772	99	·2125	·327359
65	2·169	·336260	100	·1992	·299289
66	2·007	·302547			

TABLE V.

CONVERSION OF YARDS INTO KNOTS.

Yards.	Knots.	Yards.	Knots.	Yards.	Knots.	Yards.	Knots.
1	·000493	31	·015278	61	·030064	91	·044850
2	·000986	32	·015771	62	·030557	92	·045343
3	·001479	32	·016264	63	·031050	93	·045836
4	·001971	34	·016757	64	·031542	94	·046329
5	·002464	35	·017250	65	·032035	95	·046822
6	·002957	36	·017743	66	·032528	96	·047315
7	·003450	37	·018326	67	·033021	97	·047808
8	·003943	38	·018728	68	·033514	98	·048301
9	·004436	39	·019221	69	·034007	99	·048794
10	·004929	40	·019714	70	·034500	100	·049287
11	·005421	41	·020207	71	·034993	200	·098571
12	·005914	42	·020700	72	·035485	300	·147856
13	.006407	43	·021193	73	·035978	400	·197141
14	·006900	44	·021686	74	·036471	500	·246427
15	·007393	45	·022178	75	·036964	600	·295712
16	·007886	46	·022671	76	·037457	700	·344998
17	·008379	47	·023164	77	·037949	800	·394283
18	·008871	48	·023657	78	·038433	900	·443568
19	·009364	49	·024150	79	·038935	1000	·492854
20	·009857	50	·024643	80	·039428	1100	·542139
21	·010350	51	·025136	81	·039921	1200	·591424
22	·010843	52	·025628	82	·040414	1300	·640710
23	·011336	53	·026121	83	·040907	1400	·689995
24	·011828	54	·026614	84	·041400	1500	·739280
25	·012321	55	·027107	85	·041892	1600	·788566
26	·012814	56	·027600	86	·042385	1700	·837851
27	·013307	57	·028093	87	·042878	1800	·887137
28	·013800	58	·028586	88	·043371	1900	·936422
29	·014293	59	·029078	89	·043864	2000	·985707
30	·014786	60	·029571	90	·044357	2029	1·000000

TABLE VI.

NATURAL SINES.

Degrees.	Sines.	Degrees.	Sines.	Degrees.	Sines.
1	·017	31	·515	61	·874
2	·035	32	·530	62	·883
3	·052	33	·545	63	·891
4	·070	34	·559	64	·899
5	·087	35	·574	65	·906
6	·105	36	·588	66	·914
7	·122	37	·602	67	·920
8	·139	38	·616	68	·927
9	·156	39	·629	69	·934
10	·174	40	·643	70	·940
11	·191	41	·656	71	·946
12	·208	42	·669	72	·951
13	·225	43	·682	73	·956
14	·242	44	·695	74	·961
15	·259	45	·707	75	·966
16	·276	46	·719	76	·970
17	·292	47	·731	77	·974
18	·309	48	·743	78	·978
19	·326	49	·755	79	·982
20	·342	50	·766	80	·985
21	·358	51	·777	81	·988
22	·375	52	·788	82	·990
23	·391	53	·799	83	·993
24	·407	54	·809	84	·995
25	·423	55	·819	85	·996
26	·438	56	·829	86	·997
27	·454	57	·839	87	·998
28	·469	58	·848	88	·999
29	·485	59	·857	89	·999
30	·500	60	·866	90	1·000

TABLE VII.

NATURAL TANGENTS.

Degrees.	Tangents.	Degrees.	Tangents.	Degrees.	Tangents.
1	·017	31	·601	61	1·804
2	·035	32	·625	62	1·881
3	·052	33	·649	63	1·963
4	·070	34	·674	64	2·050
5	·087	35	·700	65	2·145
6	·105	36	·727	66	2·246
7	·123	37	·753	67	2·356
8	·141	38	·781	68	2·475
9	·158	39	·810	69	2·605
10	·176	40	·839	70	2·747
11	·194	41	·869	71	2·904
12	·212	42	·900	72	3·078
13	·231	43	·933	73	3·271
14	·249	44	·966	74	3·487
15	·268	45	1·000	75	3·732
16	·287	46	1·036	76	4·011
17	·306	47	1·072	77	4·331
18	·325	48	1·111	78	4·705
19	·344	49	1·150	79	5·145
20	·364	50	1·192	80	5·671
21	·384	51	1·235	81	6·314
22	·404	52	1·280	82	7·115
23	·424	53	1·327	83	8·144
24	·445	54	1·376	84	9·514
25	·466	55	1·428	85	11·430
26	·488	56	1·483	86	14·301
27	·510	57	1·540	87	19·081
28	·532	58	1·600	88	28·636
29	·554	59	1·660	89	57·290
30	·577	60	1·732	90	∞

TABLE VIII.

LOGARITHM OF NUMBERS FROM 0 TO 100.

No.	0	1	2	3	4	5	6	7	8	9	Prop.
0	0	00000	30003	47712	60206	69897	77815	84510	90309	95424	
10	00000	00432	00860	01284	01703	02119	02530	02938	03342	03743	415
11	04139	04532	04922	05307	05690	06070	06446	06819	07188	07555	379
12	07918	08279	08637	08990	09342	09691	10037	10380	10721	11059	344
13	11394	11727	12057	12385	12710	13033	13354	13672	13988	14301	323
14	14613	14922	15229	15533	15836	16137	16435	16732	17026	17319	298
15	17609	17898	18184	18469	18752	19033	19312	19590	19866	20140	281
16	20412	20683	20952	21219	21484	21748	22011	22272	22531	22789	264
17	23045	23300	23553	23805	24055	24304	24551	24797	25042	25285	249
18	25527	25768	26007	26245	26482	26717	26951	27184	27416	27646	234
19	27875	28103	28330	28556	28780	29003	29226	29447	29667	29885	222
20	30103	30320	30535	30749	30963	31175	31386	31597	31806	32015	212
21	32222	32428	32633	32838	33041	33244	33445	33646	33846	34044	202
22	34242	34439	34635	34830	35025	35218	35411	35603	35793	35984	193
23	36173	36361	36549	36736	36922	37107	37291	37475	37658	37840	185
24	38021	38202	38382	38561	38739	38916	39094	39270	39445	39619	177
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	170
26	41497	41664	41830	41996	42160	42325	42488	42651	42813	42975	164
27	43136	43297	43457	43616	43775	43933	44091	44248	44404	44560	158
28	44716	44871	45025	45179	45332	45484	45637	45788	45939	46090	153
29	46240	46389	46538	46687	46835	46982	47129	47276	47422	47567	148
30	47712	47857	48001	48144	48287	48430	48572	48714	48855	48996	143
31	49136	49276	49415	49554	49693	49831	49969	50106	50243	50379	138
32	50515	50651	50786	50920	51055	51189	51322	51455	51587	51720	134
33	51851	51983	52114	52244	52375	52504	52634	52763	52892	53020	130
34	53148	53275	53403	53529	53656	53782	53908	54033	54158	54283	126
35	54407	54531	54654	54777	54900	55022	55145	55267	55388	55509	122
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703	119
37	56820	56937	57054	57171	57287	57403	57519	57634	57749	57863	116
38	57978	58093	58206	58320	58433	58546	58659	58771	58883	58995	113
39	59106	59218	59328	59439	59550	59660	59770	59879	59989	60097	110
40	60206	60314	60423	60531	60638	60745	60853	60959	61066	61172	107
41	61278	61384	61490	61595	61700	61805	61909	62014	62118	62221	104
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246	102
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246	99
44	64345	64444	64542	64640	64738	64836	64933	65031	65128	65225	98
45	65321	65418	65514	65609	65706	65801	65896	65992	66087	66181	96
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117	95
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034	92
48	68124	68215	98305	68395	68485	68574	68664	68753	68842	68931	90
49	69020	69108	69197	69285	69373	69461	69548	69636	69723	69810	88
50	69897	69984	70070	70157	70243	70329	70415	70501	70586	70672	86

TABLE VIII.—*continued.*

LOGARITHM OF NUMBERS FROM 0 TO 100—*continued.*

No.	0	1	2	3	4	5	6	7	8	9	Prop.
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517	84
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346	82
53	72428	72509	72591	72673	72754	72835	72916	72997	73078	73159	81
54	73239	73320	73399	73480	73560	73639	73719	73799	73878	73957	80
55	74036	74115	74194	74273	74351	74429	74507	74586	74663	74741	78
56	74819	74896	74974	75051	75128	75205	75282	75358	75435	75511	77
57	75587	75664	75740	75815	75891	75967	76042	76118	76193	76268	75
58	76343	76418	76492	76567	76641	76716	76790	76864	76938	77012	74
59	77085	77159	77232	77305	77379	77452	77525	77597	77670	77743	73
60	77815	77887	77960	78032	78104	78176	78247	78319	78390	78462	72
61	78533	78604	78675	78746	78817	78888	78958	79029	79099	79169	71
62	79239	79309	79379	79449	79518	79588	79657	79727	79796	79865	70
63	79934	80003	80072	80140	80209	80277	80346	80414	80482	80550	69
64	80618	80686	80754	80821	80889	80956	81023	81090	81158	81224	68
65	81291	81358	81425	81491	81558	81624	81690	81757	81823	81889	67
66	81954	82020	82086	82151	82217	82282	82347	82413	82478	82543	66
67	82607	82672	82737	82802	82866	82930	82995	83059	83123	83187	64
68	83251	83315	83378	83442	83506	83569	83632	83696	83759	83822	63
69	83885	83948	84011	84073	84136	84198	84261	84323	84386	84448	63
70	84510	84572	84634	84696	84757	84819	84880	84942	85003	85065	62
71	85126	85187	85248	85309	85370	85431	85491	85552	85612	85673	61
72	85733	85794	85854	85914	85974	86034	86094	86153	86213	86273	60
73	86332	86392	86451	86510	86570	86629	86688	86747	86806	86864	59
74	86923	86982	87040	87099	87157	87216	87274	87332	87390	87448	58
75	87506	87564	87622	87680	87737	87795	87852	87910	87967	88024	57
76	88081	88138	88196	88252	88309	88366	88423	88480	88536	88593	57
77	88649	88705	88762	88818	88874	88930	88986	89042	89098	89154	56
78	89209	89265	89321	89376	89432	89487	89542	89597	89653	89708	55
79	89763	89818	89873	89927	89982	90037	90091	90146	90200	90255	54
80	90309	90363	90417	90472	90526	90580	90634	90687	90741	90795	54
81	90848	90902	90956	91009	91062	91116	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91593	91645	91698	91751	91803	91855	53
83	91908	91960	92012	92065	92117	92169	92221	92273	92324	92376	52
84	92428	92480	92531	92583	92634	92686	92737	92789	92840	92891	51
85	92942	92993	93044	93095	93146	93197	93247	93298	93349	93399	51
86	93450	93500	93551	93601	93651	93702	93752	93802	93852	93902	50
87	93952	94002	94052	94101	94151	94201	94250	94300	94349	94398	49
88	94448	94498	94547	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94988	95036	95085	95134	95182	95231	95279	95328	95376	48
90	95424	95472	95521	95569	95617	95665	95713	95761	95809	95856	48

TABLE VIII.—*continued.*

LOGARITHM OF NUMBERS FROM 0 TO 100—*continued.*

No.	0	1	2	3	4	5	6	7	8	9	Prop.
91	95904	95952	95999	96047	96095	96142	96190	96237	96284	96332	48
92	96379	96426	96473	96520	96567	96614	96661	96708	96755	96802	47
93	96848	96895	96942	96988	97035	97081	97128	97174	97220	97267	47
94	97313	97359	97405	97451	97497	97543	97589	97635	97681	97727	46
95	97772	97818	97864	97909	97955	98000	98046	98091	98137	98182	46
96	98227	98272	98318	98363	98408	98453	98498	98453	98588	98632	45
97	98677	98722	98767	98811	98856	98900	98945	98989	99034	99078	45
98	99123	99167	99211	99255	99300	99344	99388	99432	99476	99520	44
99	99564	99607	99651	99695	99739	99782	99826	99870	99913	99957	44

Indices of Logarithms:—

Log. 4030 $= 3 \cdot 60530$
,, 403 $= 2 \cdot 60530$
,, 40·3 $= 1 \cdot 60530$

Log. 4·03 $= \cdot 60530$
,, ·403 $= \bar{1} \cdot 60530$
,, ·0403 $= \bar{2} \cdot 60530$
,, ·00403 $= \bar{3} \cdot 60530$

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WHEATSTONE'S BRIDGE.

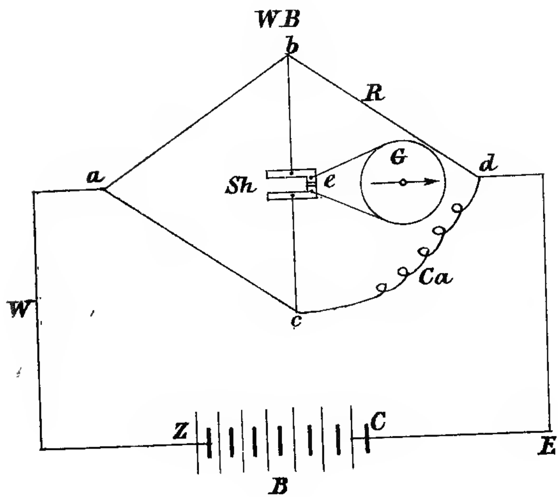


Fig. 2.

COPPER RESISTANCE TEST.

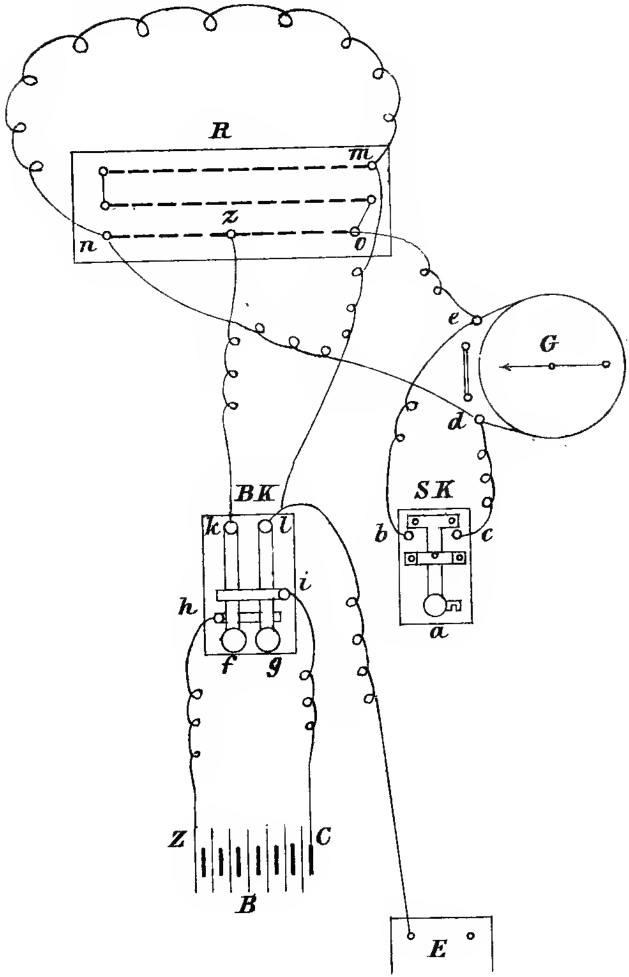


Fig. 3ª

CHARGE TEST.

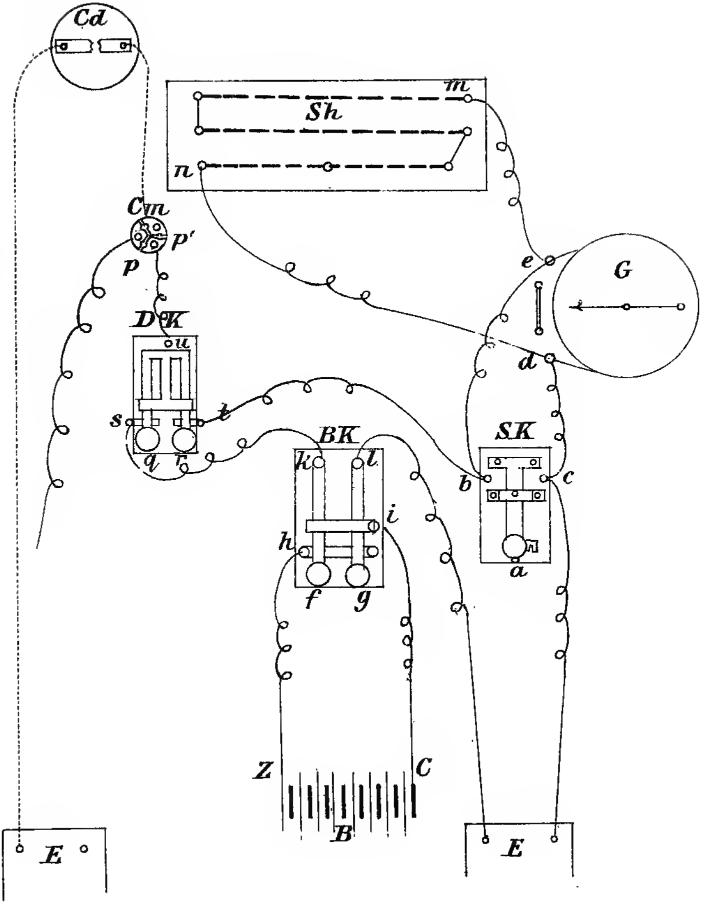
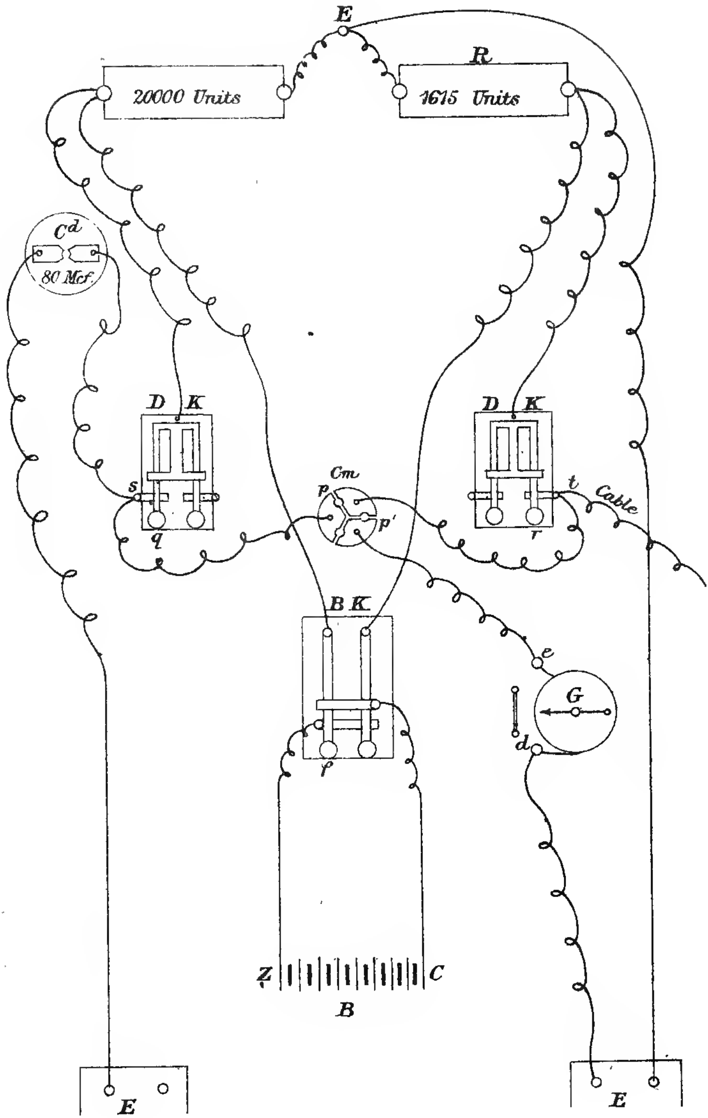


Fig. 3b.



E
R
20000 Units
1615 Units
C^d
80 Mcf.
D K
D K
s
q
Cm
p
p'
t
Cable
r
B K
e
G
d
Z
C
B
E
E

Fig. 4.

INSULATION TEST.

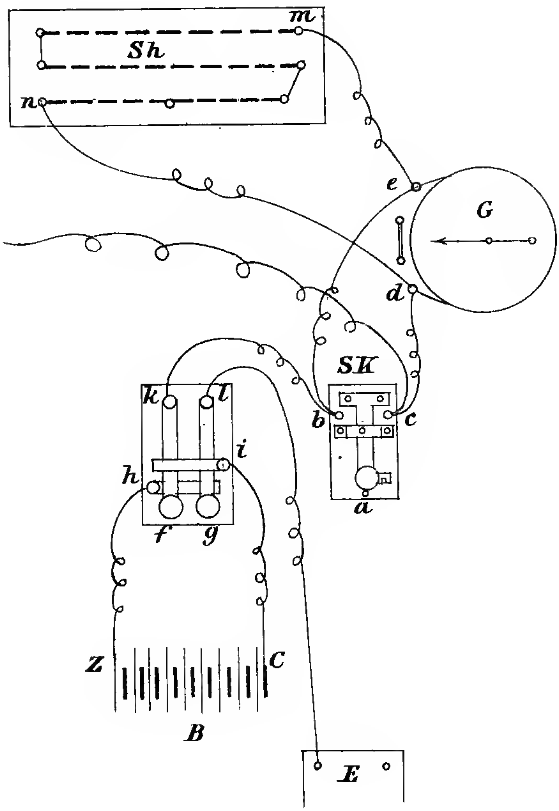


Fig. 5.

CONSTANT OF THE BATTERY.

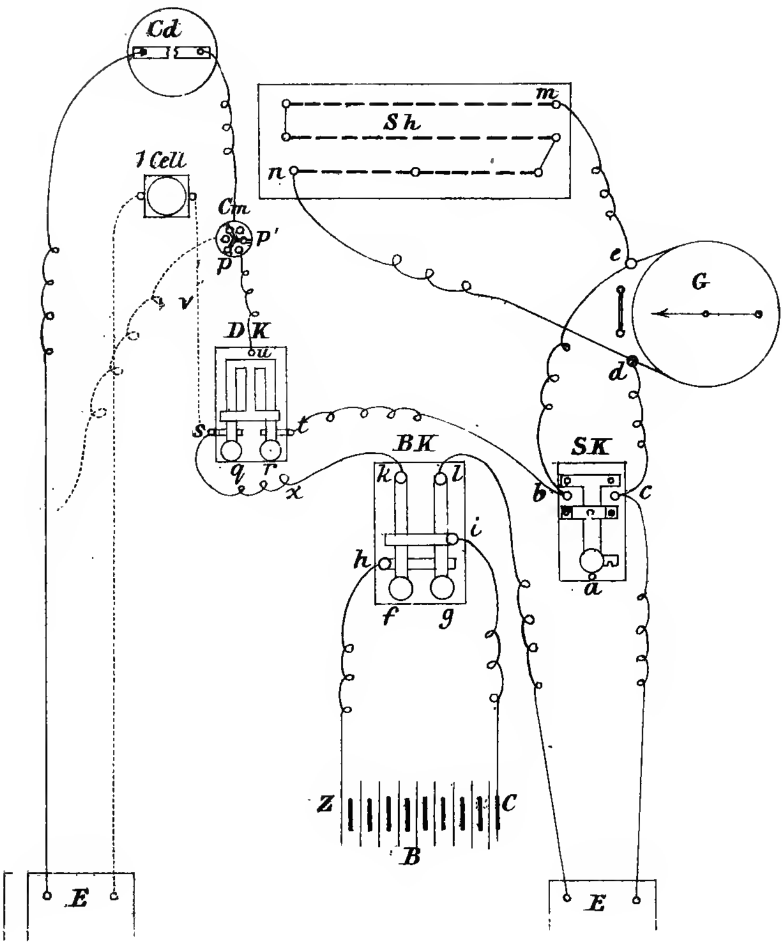


Fig 6.

CONSTANT OF THE GALVANOMETER.

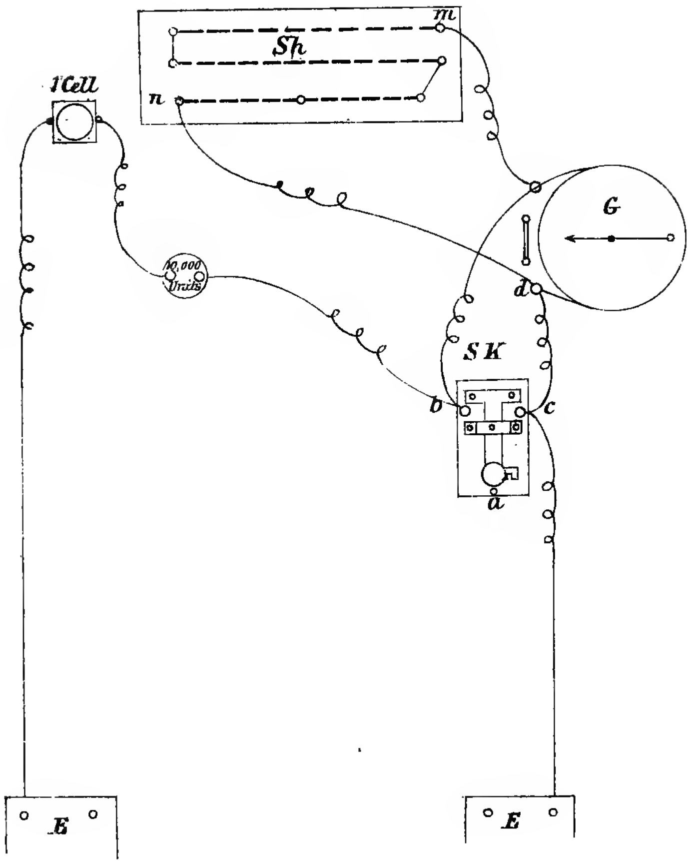


Fig. 7.

JOINT TEST.

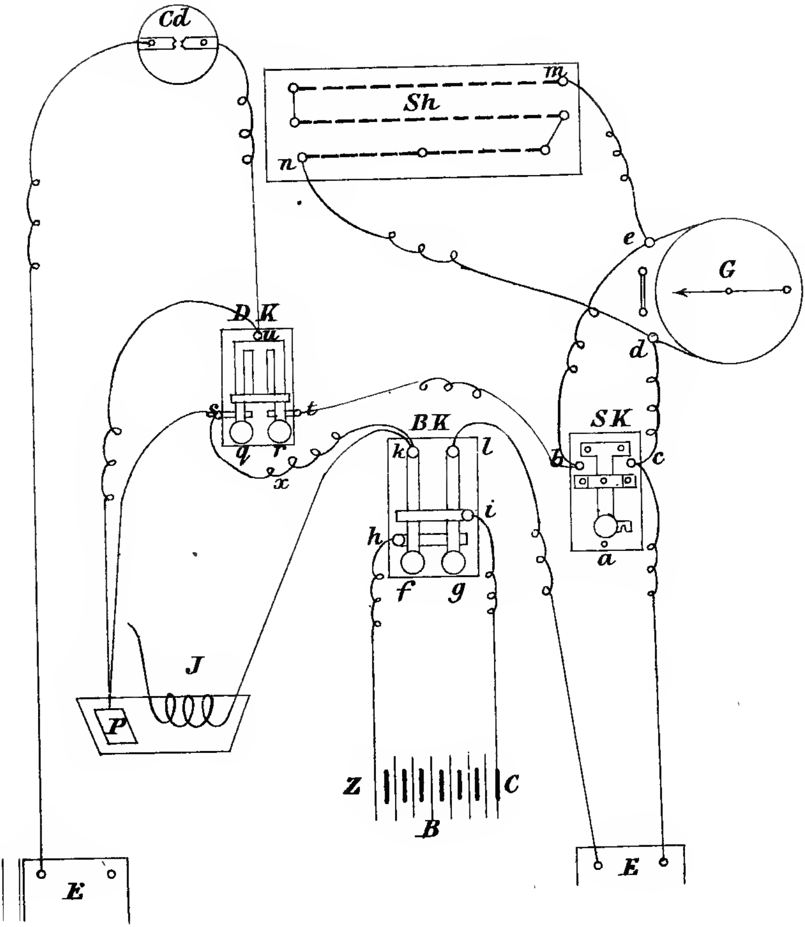


Fig. 8.

TEST FOR FAULT.

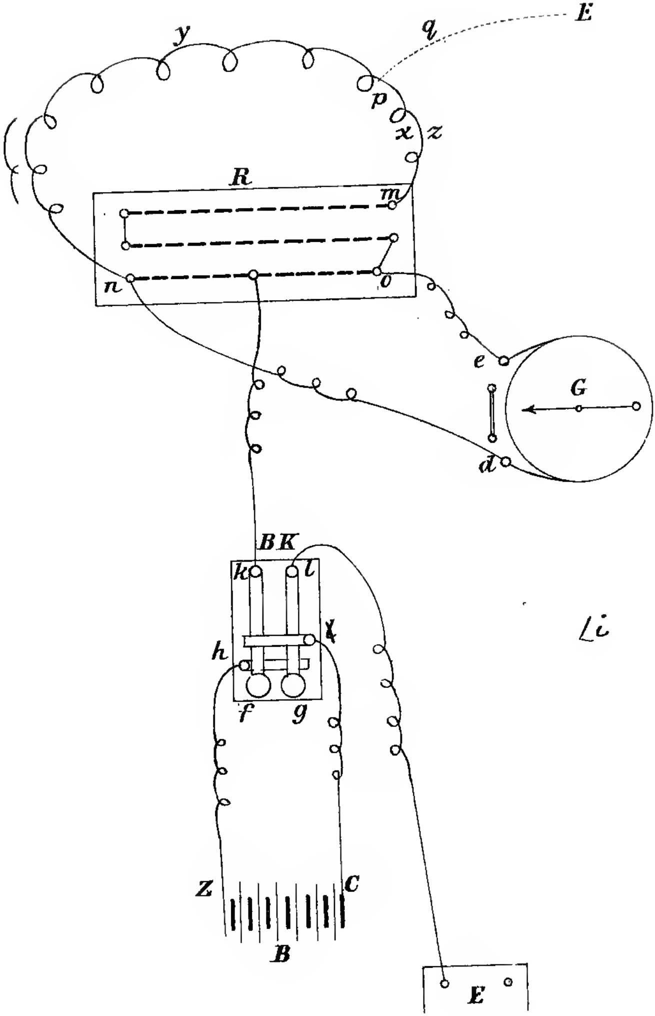


Fig. 9b.

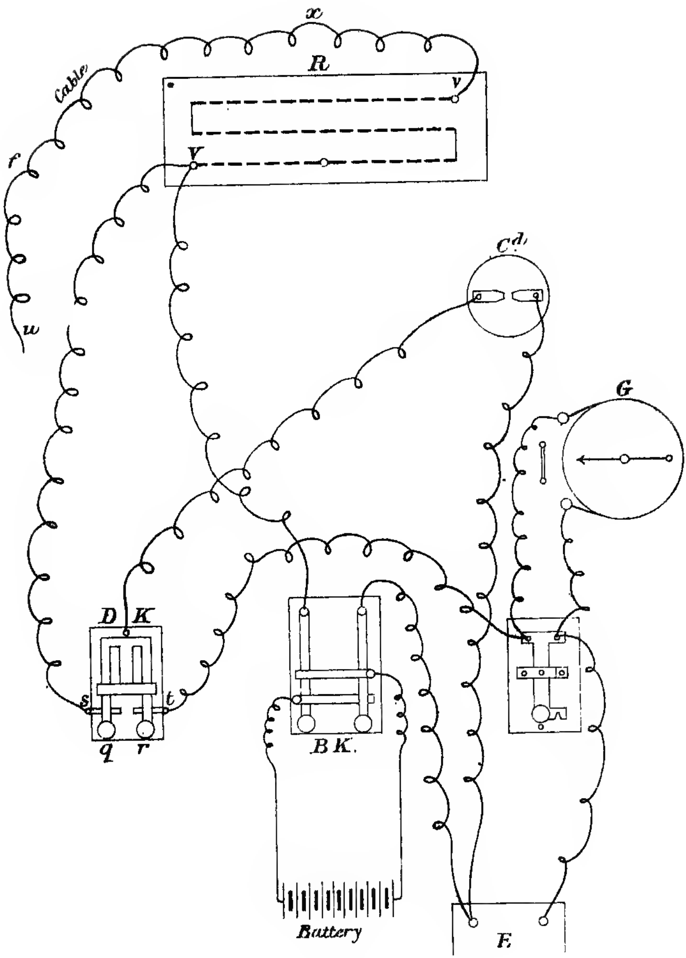


Fig. 10.

ON SHIP.

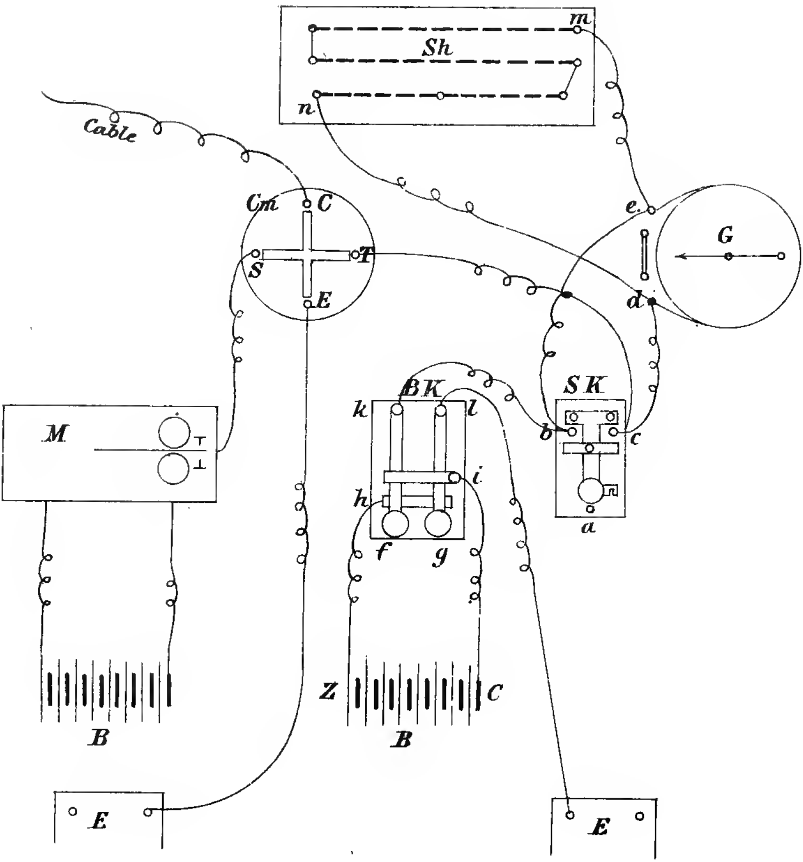


Fig. 11.

ON SHORE.